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Video Landing Parameter Survey—Honolulu International Airport

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May 2001

Final Report

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16. Abstract

The Federal Aviation Administration (FAA) William J. Hughes Technical Center is conducting a series of video landing parameter surveys at high-activity commercial airports to acquire a better understanding of typical landing contact conditions for a wide variety of aircraft and airports as they relate to current aircraft design criteria and practices.

This is the third of a series of landing parameter surveys. This report documents the results from a survey at Honolulu International Airport (HNL) performed in April 1996. Previous surveys were conducted first at John F. Kennedy International Airport (JFK) in June 1994 and later at Washington National Airport (DCA) performed in June 1995. At HNL, four video cameras were temporarily installed along the south side of runway 8L. Video images of 332 heavy, wide-body transports were captured, analyzed, and the results presented herein. Landing parameters presented include sink rate; approach speed; touchdown pitch, roll, and yaw angles and rates; off-center distance; and the touchdown distance from the runway threshold. Wind and weather conditions were also recorded and landing weights were available for most landings. Since this program is only concerned with overall statistical usage information, all data were processed and are presented without regard to the airline or flight number.

This survey has reinforced the findings from the JFK survey concerning the landing impact parameters of heavy, wide-body aircraft. The results from this survey and the prior landing parameter surveys at JFK and DCA differ substantially from aircraft sink speeds reported 35 years ago during National Aeronautics and Space Administration (NASA) surveys. No other efforts to collect operational landing data were performed by either the FAA or NASA in the interim.

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EXECUTIVE SUMMARY

The Federal Aviation Administration (FAA) William J. Hughes Technical Center is conducting a series of video landing parameter surveys at high-activity commercial airports to acquire a better understanding of typical landing contact conditions for a wide variety of aircraft and airports as they relate to current aircraft design criteria and practices.

This is the third of a series of landing parameter surveys. This report documents the results from a survey at Honolulu International Airport (HNL) performed in April 1996. Previous surveys were conducted first at John F. Kennedy International Airport (JFK) in June 1994 and later at Washington National Airport (DCA) performed in June 1995. At HNL, four video cameras were temporarily installed along the south side of runway 8L. Video images of 332 heavy, wide-body transports were captured, analyzed, and the results presented herein. Landing parameters presented include sink rate; approach speed; touchdown pitch, roll, and yaw angles; off-center distance; and the touchdown distance from the runway threshold. Wind and weather conditions were also recorded and landing weights were available for most landings. Since this program is only concerned with overall statistical usage information, all data were processed and are presented without regard to the airline or flight number.

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1. INTRODUCTION.

In an effort to better understand and document the actual operational environment of commercial jet transport aircraft landing impact conditions, the Federal Aviation Administration (FAA) William J. Hughes Technical Center initiated a series of aircraft video landing parameter surveys at high-activity commercial airports. By collecting and analyzing large quantities of video data for a wide variety of aircraft, the original design criteria and fatigue-life estimates for aircraft landing gear and support structures can be assessed and verified. The operational data will also aid in developing design requirements for future jet transports.

The use of image data to evaluate the landing performance of aircraft has been used since jet aircraft were introduced. In 1947 [1], the U.S. Navy first developed a system to characterize the typical carrier landing environment and implemented procedures to make carrier arrested landings safer. The Navy system acquired aircraft landing and approach data from the tracking and analysis of recorded 16-mm film images of the arrestment. In 1954, the National Aeronautics and Space Administration (NASA) developed a similar system using a 35-mm camera and conducted a number of surveys of commercial airplanes, the last ones in 1959 [2-7]. The difference between the two systems was that the Navy photographed from a head-on aspect along the runway apron, while NASA's camera was positioned perpendicular to the runway, approximately 900 feet from the runway centerline.

In 1967, the Navy enhanced its system by replacing the 16-mm cameras with 70-mm cameras to provide considerably greater image resolution and consequently greater accuracy [8]. Using the enhanced system, the Navy conducted over 40 landing parameter surveys. However, the data reduction phase of the research was labor intensive and limited the number of surveys which could be conducted. The search for a new improved system was concluded in 1992 when the Navy successfully developed and implemented a system that uses adaptive video imaging and tracking technology for their surveys. The performance and accuracy of this system is documented in references 9 and 10. Shortly thereafter, the FAA and the Navy transitioned the newly developed video technology to commercial operations [11].

The objectives of the FAA landing parameter survey program are to acquire large amounts of typical transport operational data to (1) validate and update NASA TN D 4529 which was derived from usage data measured during the 1950s, (2) provide detailed characterization of typical transport airplane landing velocities and angular displacements, and (3) determine if there is a trend towards higher sink rates at higher gross weights.

The first of the FAA's commercial aircraft video landing surveys was conducted in 1994 at John F. Kennedy International Airport (JFK), runway 13L, to collect large quantities of wide-body jet aircraft data [12]. The second survey was performed in 1995 at Washington National Airport (DCA) which collected landing parameters for flight operations using a shorter runway [13]. The principle runway (runway 36) at DCA is 7000 ft long and cannot handle aircraft larger than the Airbus A-320 and Boeing 757.

This survey was performed to determine if the results of previous surveys were biased because of the challenging aircraft approaches and operating conditions at those airports. As a result, it was suggested that operations at Honolulu International (HNL) were more benign than the other airports survey. Also, preliminary conclusions on the landing performance of wide-body aircraft were questionable, and a location with a significant number of wide-body aircraft operations was required. The survey team can only instrument one end of one runway, so Honolulu, with the vast majority of landings on runway 8L, maximized the collection of wide-body data.

Video images of aircraft landing on runway 8L were recorded by a series of four cameras temporarily installed on the edge of the runway. Runway 8L was selected for it is the primary runway used for landing. Runway 8R is used almost exclusively for takeoffs due to aircraft noise considerations. The survey data was collected over a 10-day period in March and April 1996. These video images were stored on an optical disk recorder, processed, and analyzed at the Naval Air Warfare Center, and the resulting landing parameter information was forwarded to the William J. Hughes Technical Center.

Since the primary goal of the survey is to collect statistical information on actual operations, the identity of individual aircraft, airlines, flight numbers, and dates are purposefully omitted from the report. Aircraft landing performance was analyzed only on the basis of aircraft category, model, type, and wind conditions.

2. SYSTEM DESCRIPTION.

Modern developments in video technology permitted the Navy to transition its landing parameter data analysis system from using photographic film to one using video technology. The Navy video system is known as the Naval Aircraft Approach and Landing Data Acquisition System (NAALDAS). The system consists of a high-resolution frame grab video camera, a laser disk recorder, and a computer control unit. The key to the NAALDAS system is a highly modified video camera. The camera's enhanced vertical resolution (double that of standard video formats) permits highly accurate measurement and tracking of aircraft position data. The camera is supported by an image analysis system using image processing technology. Particular image features (landing gear wheels, wing tips, flaps, or engine inlets) are tracked in successive images, and this information is used to determine the relative motion of the aircraft. The combination of camera resolution and image processing technology permits the location of image features to be determined within 0.1 pixel. The technique is as accurate, yet more efficient than the Navy's previously used 70-mm film system.

NAALDAS was designed to cover the restricted touchdown area on an aircraft carrier using a single camera. To support the commercial application, the FAA funded the design and development of a modified, multiple-camera configuration of NAALDAS using four video cameras located along the edge of the runway. The images from these cameras are recorded sequentially as the aircraft passes through their field of view. The use of four cameras expands the system coverage area to approximately 2000 ft along the anticipated touchdown region of the runway. Fiber-optic signal cables are used to eliminate interference and line losses between the cameras and the recording station. The modified configuration of NAALDAS was successfully tested in February 1994 at the William J. Hughes Technical Center, Atlantic City International Airport (ACY), New Jersey. Figure 1 shows a camera in operation on a commercial runway.

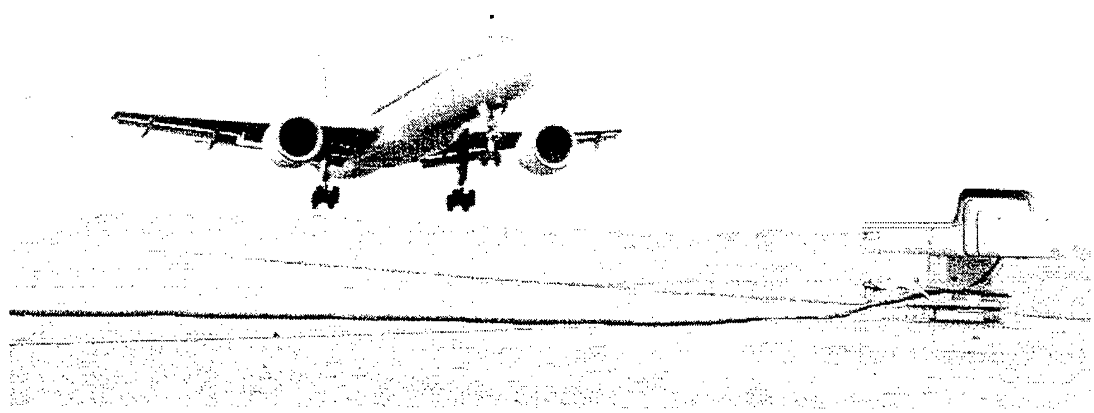

FIGURE 1. VIDEO CAMERA IN OPERATION DURING COMMERCIAL LANDING PARAMETER SURVEY

The video cameras are installed on the edge of the runway, facing the approaching aircraft. The cameras are located approximately 700 feet apart, starting 1700 feet from the end of the runway, and usually located in line with the runway edge lights, which at HNL are approximately 800 ft off the runway centerline. The camera is aimed at the center of the targeted touchdown area. The camera's aim is fixed and does not track the aircraft. Figure 2 is a schematic of the multiple-camera configuration.

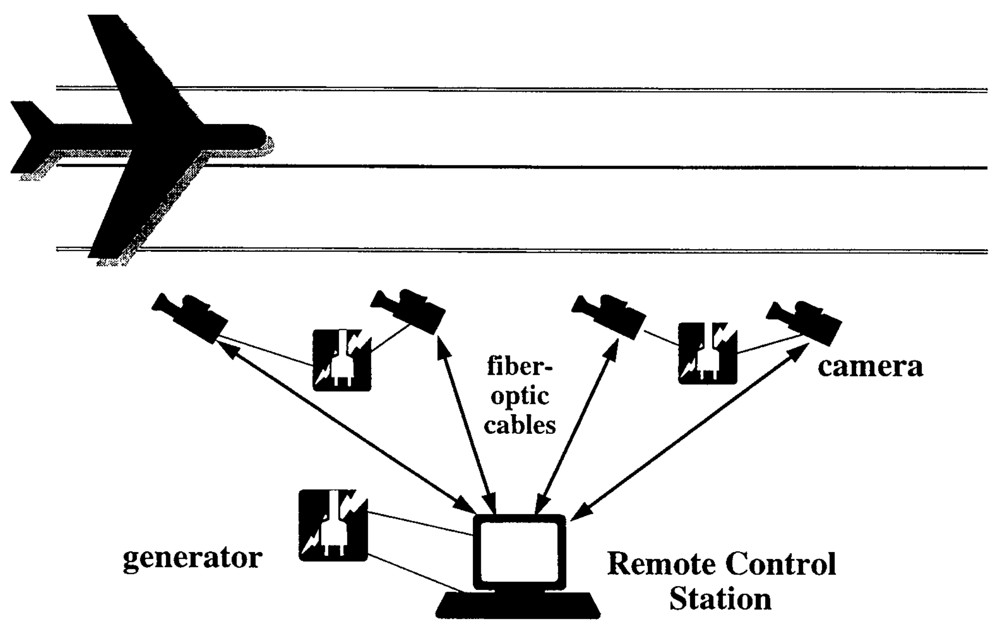

FIGURE 2. FAA LANDING LOADS CAMERA SETUP

The NAALDAS video cameras have a fixed field of view. Each camera is aligned and calibrated against temporary alignment targets which are placed on the runway for that purpose. These targets are placed in surveyed locations, and the target images are recorded as a calibration sequence. This sequence is processed to generate a transformation matrix to relate image measurements to the runway.

The NAALDAS data recording system is operated from a vehicle parked in a safe location near the touchdown region of the survey runway. Judicious selection of this parking location is required to prevent any interference with airport operations. At HNL, the data recording system vehicle was located approximately 350 ft from the runway centerline. Temporary cabling is run from the vehicle to the cameras and the vehicle remains in the chosen location during flight operations. The system is powered entirely with portable electrical generators. Currently, NAALDAS is limited to coverage of one end of a runway and cannot be relocated to accommodate runway changes. This restriction exists since the cameras must be precisely aimed and recalibrated if they are relocated, which requires the runway be closed.

The aircraft image is captured on an optical laser disk recorder for subsequent analysis on the NAALDAS analysis system workstation. Approximately 60 landings can be stored on a disk. An identity number is assigned to the disk, and event numbers are assigned to each video sequence. The use of video disks eliminates film processing cost and time.

Image enhancement and automatic data point tracking are performed using the analysis workstation. This provides position time information of image features on the aircraft. Each individual airplane landing is identified by model type and serial number so that the necessary physical dimensions and geometric locations can be correlated with the time-tracked video images. The data reduction system software then derives the landing impact parameters, i.e., sinking speed, horizontal velocity, bank angle, crab angle, etc.

The analysis station consists of a Sun computer workstation with an image processing board, laser disk player, computer monitor, high-resolution monitor, and associated power regulator and cables. The station operator automatically tracks the video image features during the landing sequence. By positioning windows over the desired image feature, the operator prepares the system to track that feature through the entire sequence. Multiple-image features can be tracked simultaneously using multiple windows. The operator has the capability to select image threshold levels, image enhancement formats, and algorithms. The operator can also select the type of tracking (edge or centroid) to be used to allow the system to automatically track the image, eliminating the errors in data reduction which were inherent in the manual tracking procedures used with the 70-mm film system. The centroid tracking algorithm enables the system to locate image features with subpixel accuracy.

Once the image sequence is tracked, the pixel information is transformed, digitized, and entered into the landing parameter analysis software. The software takes image position information, determines the change in image feature position of successive frames at a rate of 30 frames per second, and generates position time curves for the feature.

The analysis of image data provides the aircraft's closure speed with respect to the camera. The reported value of approach speed is the sum of closure speed and the component of wind parallel to the centerline of the runway. The wind speed and direction information measured using an anemometer situated near the touchdown location was used to calculate the approach speed.

In addition to the video images, from which the ground contact parameters are derived, other data describing each landing are collected during the video survey to determine which set of geometric data to use in the analysis. An anemometer, temporarily installed near the survey site, collected wind speed and direction for each landing. An estimate of the aircraft's touchdown landing weight was provided by the aircraft operators.

3. DISCUSSION.

3.1 OPERATIONS AT HNL INTERNATIONAL AIRPORT.

The HNL survey was designed to obtain as large a quantity of heavy, wide-body (B-747, DC-10, L-1011, and MD-11) aircraft landings as possible. Prior to the survey, both the FAA Airports and the HNL Operations personnel indicated that, during a 10-day survey period, there would be little difficulty recording 300 heavy, wide-body landings at HNL. In addition, they stated that tropical easterly trade winds make runway 8L the primary daytime runway for landing the larger wide-body airplanes. Figure 3 shows the Department of Defense (DoD) Flight Information Publication diagram for HNL. The reef runway (8R) usually handles the wide-body takeoffs to reduce the effect of aircraft noise on the city. Given this information, runway 8L was selected as the runway to install the camera system. The survey team decided to collect landing data for both wide-body and narrow-body airplanes.

The quantity of wide-body landings was as expected with no unusual approach procedures. The wide-body airplanes would follow an 8 to 10 mile straight-in approach over Barbers Point, touch down within the range of the cameras and exit the runway near the overseas terminal at taxiway S or H (7250 ft and 8200 ft from runway 8L threshold). Frequent informal Land and Hold Short (LAHSO) procedures were also observed.

The narrow-body interisland operations, however, proved to be quite a surprise for the joint FAA/Navy survey team. After touchdown, nearly every DC-9 or B-737 airplane would exit the runway at either taxiway L or G (4900′ and 5400′ from runway 8L threshold, respectively) to expedite arrival at the interisland terminal. This custom would, in effect, shorten a 12,357-foot runway to approximately 5000 feet. Added to this, approximately 60% of the narrow-body aircraft would opt to make a curved approach from the south rather than using the Barbers Point straight-in approach.

Unfortunately, records for individual landings were not kept on curved approaches and LAHSO operations, thus, the possible effect of continually shortening the effective runway and the curved approaches on the touchdown vertical velocities is not known.

3.2 HONOLULU INTERNATIONAL AIRPORT CONDITIONS.

The video landing survey data acquisition equipment was installed on the south side of runway 8L, a 150-foot-wide, 12,360-foot-long runway. Runway 8L was selected after observing flight operations and reviewing historical landing runway operations data. In addition, suitable camera positions were available. Once the survey cameras are installed and calibrated, they cannot be moved to adjust to changes in operation caused by wind shifts. This was not a problem during this survey.

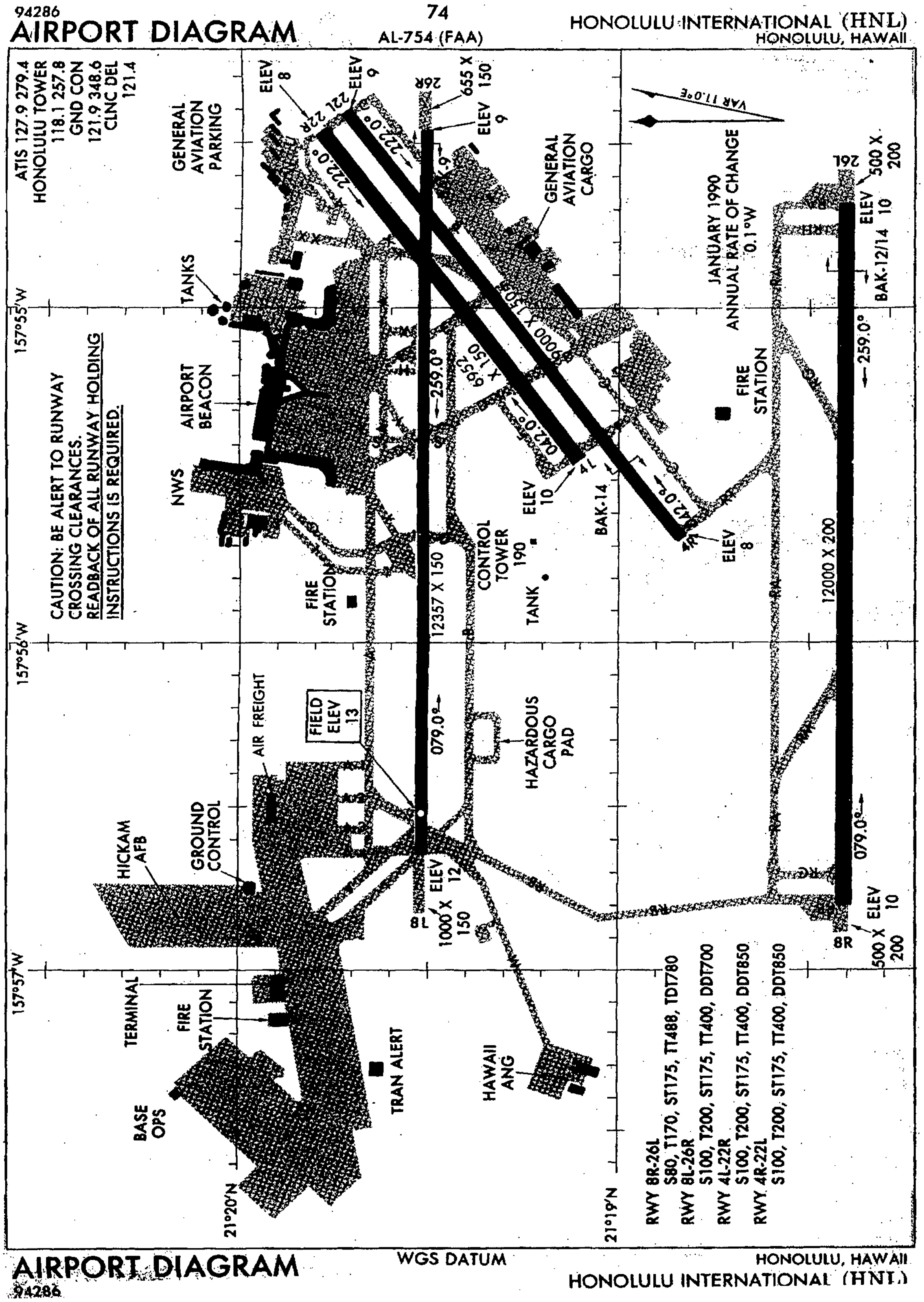

FIGURE 3. HONOLULU INTERNATIONAL AIRPORT DIAGRAM

Video images from a total of 332 landings from the survey at HNL were processed and analyzed. This includes 145 Boeing 747s, 39 Lockheed L-1011s, 148 McDonnell Douglas DC-10s, 11 B-767s and 9 MD-11s. Although the survey team captures nearly 300 landings of B-737 and DC-9 airplanes, the results of the analysis of these are being deferred to a later time*. The camera installation was optimized for collection of the larger images with camera further separated from one another as to minimize the quantity of heavy wide bodies which touchdown outside the camera's field of view. This wide-body optimization resulted in video images of narrow-body jets being somewhat smaller than was found from other surveys.

Regarding the HNL survey, the main focus was the collection of large quantities of heavy, wide-body landings to compare to those collected at JFK in 1994. It was assumed that the landing sink rates would be benign in the tropical environment with relatively mild and consistent easterly trade winds. Given the long straight-in approach using the wide-body aircraft and the excellent year round weather this assumption appeared reasonable. There was considerable concern on the part of industry that the runway 13L at JFK required pilots to make a sharp turn in the landing pattern. Additionally, runway 13L at JFK, considerable crosswinds (sea breeze) during the hot summer afternoons existed.

At HNL, runway 8L is a 12,360 ft runway. However, the interisland terminal is located at taxiway G, less than halfway down the runway from the approach end of runway 8L (figure 3). Interisland aircraft consistently turned off the runway at taxiway G to save time taxiing to the terminal. Interisland aircraft consisted of narrow-body aircraft, B-737 and DC-9 aircraft. This procedure reduced the effective length of the runway to something less than that at DCA. In addition, many of the narrow-body airplane pilots used the visual flight rules (VFR) approach procedure, which used a 90-degree turn onto a final approach. Heavy, wide-body airplane pilots used the 10 mile straight-in approach over Barbers Point.

From figure 3, runways 4L-22R and 4R-22L intersect runway 8L at its eastern end. Pilots landing on runway 8L were routinely requested to land and hold short of runway 4L. This effectively reduced the runway available for landing the wide-body aircraft. In addition, the location of the main terminal near taxiways Y and I encouraged the pilot to turn off the runway at those points. This effectively reduces the runway's usable length to less than that at JFK runway 13L. Comparison of the wide-body landings at these airports support this conclusion.

3.3 HONOLULU INTERNATIONAL AIRPORT SURVEY RESULTS.

Landing parameters for 332 heavy, wide-body aircraft landings were calculated using the procedures described in references 8 and 10. Table 1 summarizes the primary landing parameters for the four heavy, wide-body airplane models covered in this survey. The table provides the mean and standard deviation and the number of observations for selected landing parameters.

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* Up to this date, all of the data reduction and analysis has been performed by the Naval Air Warfare Center (NAWC) in Patuxent River, MD. Because of the large amount of data reduction being accomplished at the NAWC, the FAA is developing its own enhanced data reduction process. These smaller image narrow-body jet images are planned to be reduced and analyzed by this new FAA facility.

TABLE 1. SURVEY PARAMETER COMPARISON BY AIRCRAFT MODEL—
HEAVY, WIDE-BODY JET TRANSPORTS

Heavy, Wide-Body Jet Transports									
Aircraft Model	Number of Events		Closure Speed (kts)	Approach Speed (kts)	Sink Speed (ft/sec)	Pitch Angle (deg)	Roll Angle (deg)	Yaw Angle (deg)	Distance From Runway Threshold
B-747	125	Average	139.0	143.1	2.99	5.86	-2.33	-1.59	1992
DC-10	148	Average	148.9	153.5	3.44	8.65	-2.57	-1.69	1730
L-1011	39	Average	148.6	154.2	3.29	10.43	-2.25	-2.43	1793
MD-11	9	Average	154.8	157.4	3.42	7.39	-2.63	-2.91	1877

The sample sizes for the B-747 and the DC-10 airplanes are large enough to make some general observations regarding the data. The power approach airspeed for the three-engine jets appears to bc approximately 10 knots higher than for the four-engine B-747. Similarly, in all cases, the sink speed of the three-engine jets was higher than that of the B-747 airplane. Three-engine jet touchdown pitch angles were consistently higher than for those of the B-747. Consistent negative roll and yaw angles demonstrate that the data obtained for each model was from similar crosswind conditions.

More detailed statistical summaries for individual model types are provided in tables 2 through 6. The values of landing parameters determined for individual landings, sorted by airplane model type, are provided in appendix A. Landing parameter survey definitions in appendix B provide an explanation of the symbols and definition of parameters used.

In tables 2 through 6 the number of landings for the aircraft reported landing weight is less than for other data because the landing weights were not obtained for all operators. Landing weight data, was obtained for 277 of the 322 landings or nearly 85 percent. Table 6 summarizes 11 B-767 events, which are the only, nonheavy, wide-body airplane summarized in subject report.

Figures 4, 5, and 6 contain sink speed distributions for the B-747, DC-10, and L-1011 airplanes, respectively. These distributions are somewhat similar in shape with all three positively skewed. Skewness is a descriptive statistic, which is defined as the measure of the departure of a frequency distribution from symmetry. In a positively skewed distribution, the departure from symmetry is greatest at values above the mean. Positively skewed distributions will typically contain the majority of data points, the mean and the distribution will have an elongated tail. When one is interested in extrapolating sample collected over an entire fleet, the shape of the distribution is a major consideration which must be accounted for.

TABLE 2. STATISTICAL SUMMARY—MODEL B-747

Aircraft Model B-747				
Parameter	Mean Value	Standard Deviation	Measurement Units	Number of Landings
Sinking Speed: Port Wheel	2.86	2.22	ft/sec	125
Starboard Wheel	3.06	2.05	ft/sec	125
Average of Main Wheels	2.99	1.71	ft/sec	125
Closure Speed (Measured to Camera)	139	10	knots	125
Approach Speed	143.1	9.3	knots	125
Wind Speed: Parallel Component	4.14	5.47	knots	125
Perpendicular Component	-2.27	4.38	knots	125
Pitch Angle at Touchdown	5.86	1.65	degrees	125
Roll Angle at Touchdown	-2.33	1.56	degrees	125
Yaw Angle at Touchdown	-1.59	4.99	degrees	125
Calculated Glide Slope Angle	1.04	0.15	degrees	125
Distance From Touchdown to Runaway Threshold	1992	569	feet	125
Off-Center Distance at Touchdown	-3.71	6.27	feet	125
Aircraft Reported Landing Weight	483734	31498	pounds	105

TABLE 3. STATISTICAL SUMMARY—MODEL DC-10

Aircraft Model DC-10				
Parameter	Mean Value	Standard Deviation	Measurement Units	Number of Landings
Sinking Speed: Port Wheel	3.24	2.11	ft/sec	148
Starboard Wheel	3.59	2.26	ft/sec	148
Average of Main Wheels	3.44	1.89	ft/sec	148
Closure Speed (Measured to Camera)	148.9	13.1	knots	148
Approach Speed	153.5	12.1	knots	148
Wind Speed: Parallel Component	4.61	5.91	knots	148
Perpendicular Component	-1.55	5.99	knots	148
Pitch Angle at Touchdown	8.65	1.84	degrees	148
Roll Angle at Touchdown	-2.57	1.86	degrees	148
Yaw Angle at Touchdown	-1.69	4.6	degrees	148
Calculated Glide Slope Angle	1.05	0.12	degrees	148
Distance From Touchdown to Runaway Threshold	1730	571	feet	148
Off-Center Distance at Touchdown	-1.5	6.1	feet	148
Aircraft Reported Landing Weight	349059	21892	pounds	132

TABLE 4. STATISTICAL SUMMARY—MODEL L-1011

Aircraft Model L-1011					
Parameter		Mean Value	Standard Deviation	Measurement Units	Number of Landings
Sinking Speed:	Port Wheel	3.01	1.77	ft/sec	39
	Starboard Wheel	3.49	1.54	ft/sec	39
Average of Main Wheels		3.29	1.37	ft/sec	39
Closure Speed (Measured to Camera)		148.6	10.6	knots	39
Approach Speed		154.2	8.8	knots	39
Wind Speed:	Parallel Component	5.61	6.12	knots	39
	Perpendicular Component	-1.56	7.17	knots	39
Pitch Angle at Touchdown		10.43	1.59	degrees	39
Roll Angle at Touchdown		-2.25	2.34	degrees	39
Yaw Angle at Touchdown		-2.43	4.99	degrees	39
Calculated Glide Slope Angle		1.03	0.1	degrees	39
Distance From Touchdown to Runaway Threshold		1793	715	feet	39
Off-Center Distance at Touchdown		-3.05	6.82	feet	39
Aircraft Reported Landing Weight		335381	10531	pounds	29

TABLE 5. STATISTICAL SUMMARY—MODEL MD-11

Aircraft Model MD-11					
Parameter		Mean Value	Standard Deviation	Measurement Units	Number of Landings
Sinking Speed:	Port Wheel	3.07	2.27	ft/sec	9
	Starboard Wheel	3.52	2.47	ft/sec	9
Average of Main Wheels		3.42	2.12	ft/sec	9
Closure Speed (Measured to Camera)		154.8	11.5	knots	9
Approach Speed		157.4	10.4	knots	9
Wind Speed:	Parallel Component	2.59	5.07	knots	9
	Perpendicular Component	-0.52	4.79	knots	9
Pitch Angle at Touchdown		7.39	1.01	degrees	9
Roll Angle at Touchdown		-2.63	2.31	degrees	9
Yaw Angle at Touchdown		-2.91	3.82	degrees	9
Calculated Glide Slope Angle		1.08	0.15	degrees	9
Distance From Touchdown to Runaway Threshold		1877	510	feet	9
Off-Center Distance at Touchdown		-2.78	5.89	feet	9
Aircraft Reported Landing Weight		376486	18605	pounds	8

TABLE 6. STATISTICAL SUMMARY—MODEL B-767

Aircraft Model B-767					
Parameter		Mean Value	Standard Deviation	Measurement Units	Number of Landings
Sinking Speed:	Port Wheel	3.1	1.36	ft/sec	11
	Starboard Wheel	4.24	1.12	ft/sec	11
Average of Main Wheels		3.76	0.93	ft/sec	11
Closure Speed (Measured to Camera)		138.4	11.7	knots	11
Approach Speed		146.7	9.2	knots	11
Wind Speed:	Parallel Component	8.23	6.07	knots	11
	Perpendicular Component	-3.18	4.68	knots	11
Pitch Angle at Touchdown		5.4	1.8	degrees	11
Roll Angle at Touchdown		-3.08	1.94	degrees	11
Yaw Angle at Touchdown		-3.91	4.21	degrees	11
Calculated Glide Slope Angle		0.96	0.1	degrees	11
Distance From Touchdown to Runaway Threshold		1699	436	feet	11
Off-Center Distance at Touchdown		-6.91	4.91	feet	11
Aircraft Reported Landing Weight		263435	14388	pounds	3

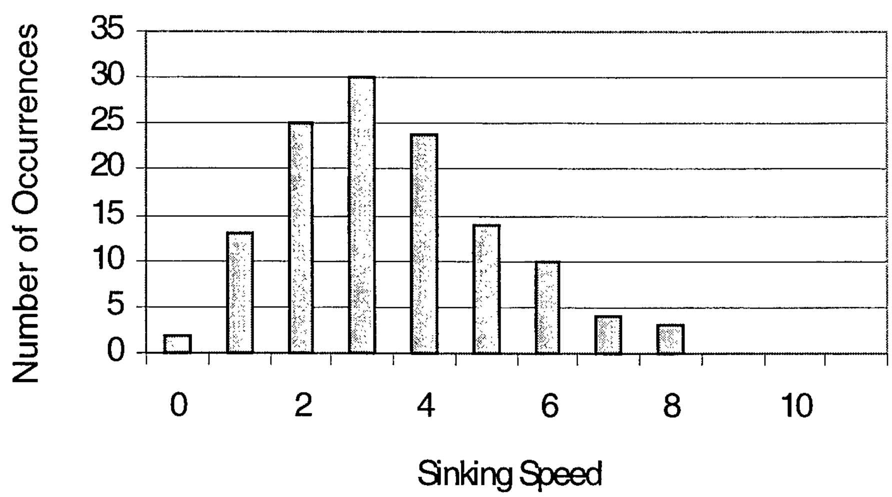

FIGURE 4. HONOLULU SURVEY, B-747s

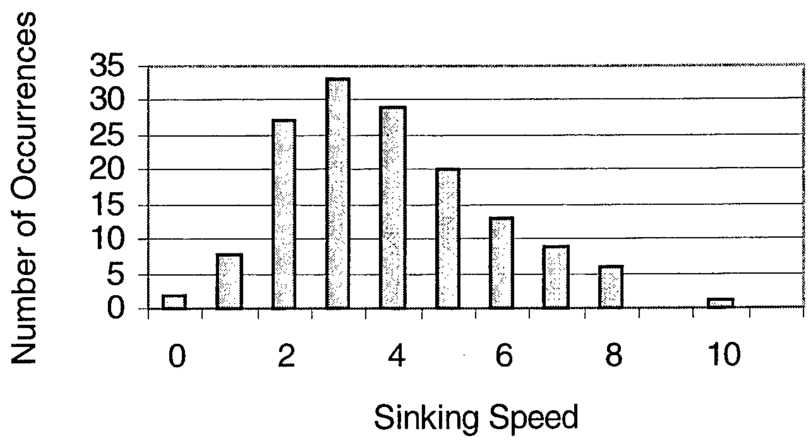

FIGURE 5. HONOLULU SURVEY, DC-10s

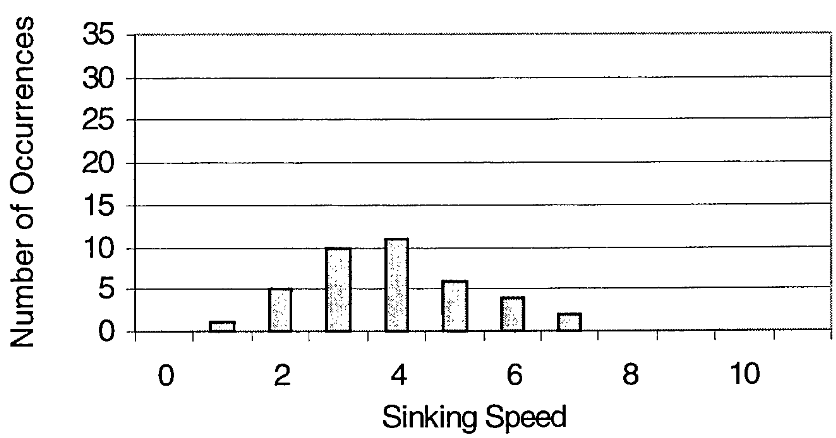

FIGURE 6. HONOLULU SURVEY, L-1011s

The same figures also show that the sink speeds for the three-engine jets, DC-10s, and L-1011s appear to have a slightly higher distribution than that of the four-engine B-747s. This is further exemplified in figure 7, where the sink speeds for the three-engine wide-bodies are compared, in probability form, with the four-engine sink speed distribution. Contained also in figure 7 is the MIL-A-8866 sink speed distribution for military transports.

Figure 7 is plotted on a semilog scale. Assume that a vertical line existed at 6 feet per second. The MIL-A-8866 distribution indicates, that over a lifetime, a military transport fleet would be designed for the assumption that three percent of the sink speeds would be in excess of 6 feet per second. During the Honolulu survey in March-April 1996, nearly 10 percent of the three-engine heavy, wide-body jet sink speeds exceeded 6 feet per second, while nearly eight percent of the four-engine heavy, wide-body jets exceeded the same 6 feet per second. This topic is addressed further in section 3.3, comparison of HNL survey results with those of the JFK survey in June 1994.

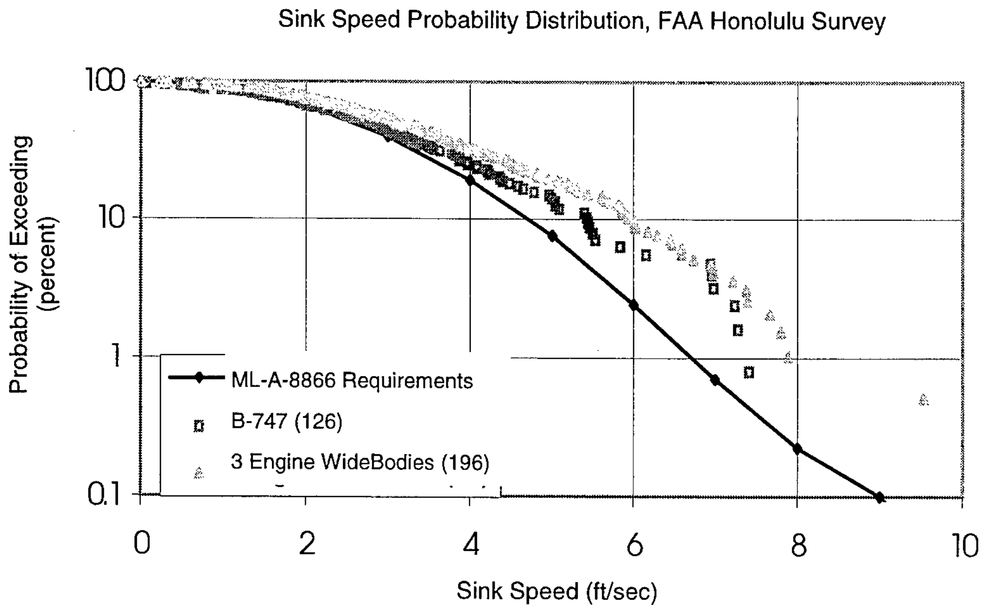

FIGURE 7. SINK SPEED PROBABILITY DISTRIBUTION

Figures 8 through 12, however, present some overall observations regarding the combined 322 measured parameters of landing touchdown from subject video landing survey. Data for B-767 aircraft were not included in these figures.

Figure 8 is a plot of sink speed vs touchdown distance from the runway threshold. The figure indicates that the span of camera coverage was approximately from 700 to 3200 feet from the threshold. The straight line (statistical trend line) indicates that the sink speed of the touchdowns occurring near 1000 feet from the threshold are approximately twice those landings where touchdown is near the 3000 foot mark.

Figure 9 is a plot of sink speed vs approach speed. For the same airplane types, higher approach velocities should translate into higher sink speed. From figure 9, one can quantify the contribution of approach velocity to sink speed. Figure 10 shows a plot of approach speed against pitch angle. Figure 11 is a plot of touchdown roll angle vs crosswind while figure 12 is a plot of touchdown yaw angle vs crosswinds. Statistical linear trend lines are provided on each figure. The authors believe that the identification of the existence of the relations presented, while somewhat intuitive, add considerable creditability to the video landing parameter survey system and the results presented herein. Readers are left to draw whatever additional conclusions they want from figures 8 through 12 and all of the other reported data in this survey.

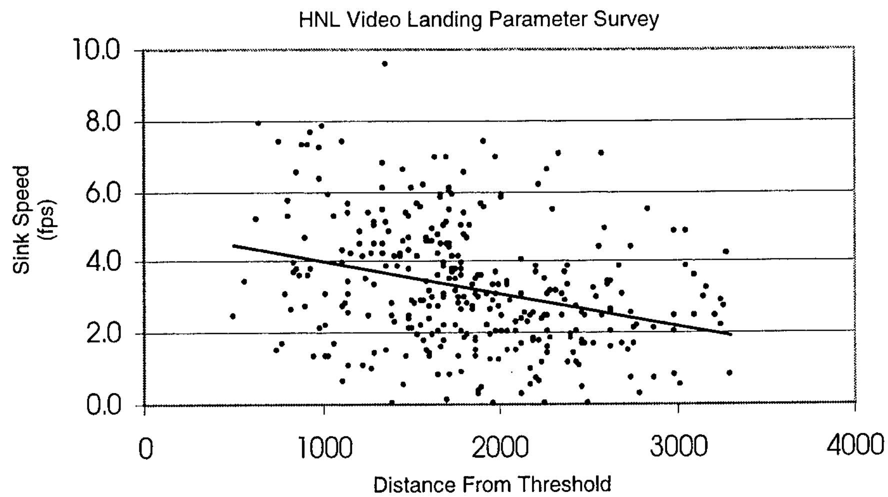

FIGURE 8. SINK SPEED VS DISTANCE FROM THRESHOLD

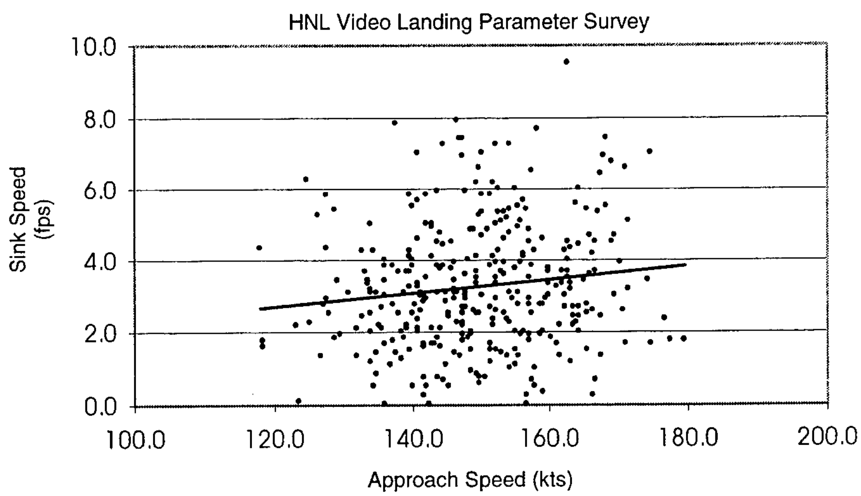

FIGURE 9. SINK SPEED VS APPROACH SPEED

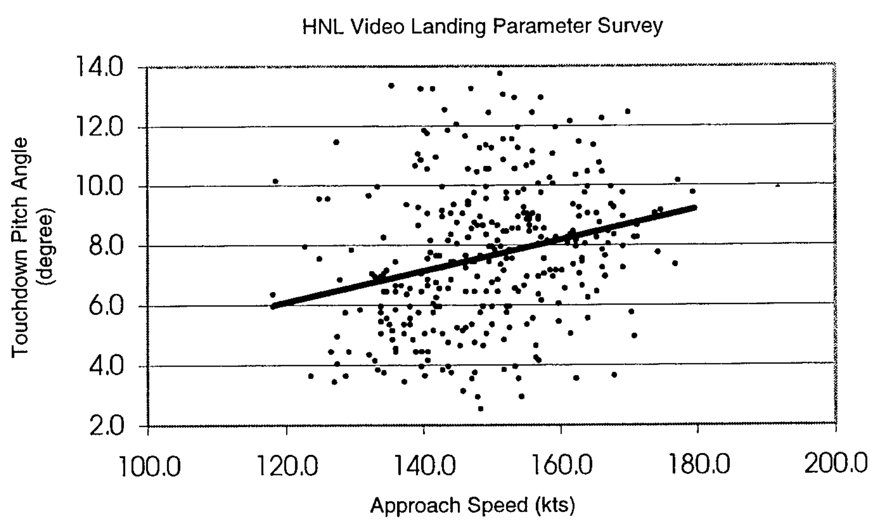

FIGURE 10. TOUCHDOWN PITCH ANGLE VS APPROACH SPEED

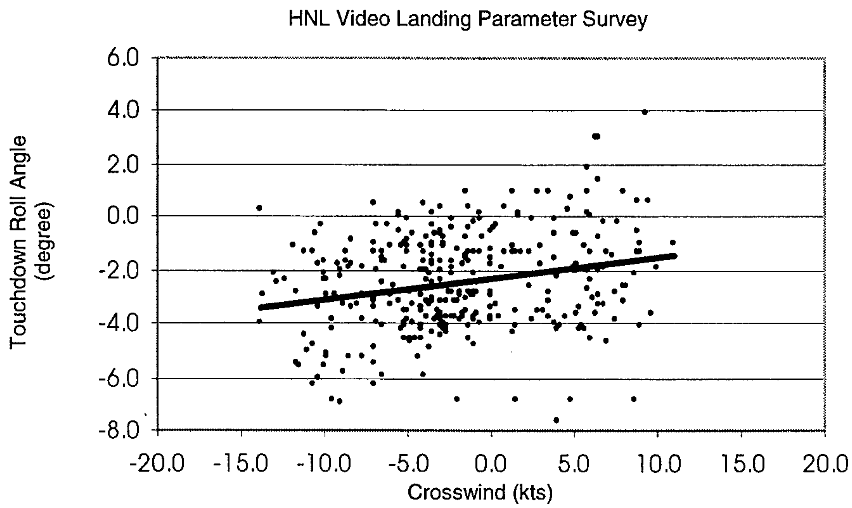

FIGURE 11. TOUCHDOWN ROLL ANGLE VS CROSSWIND

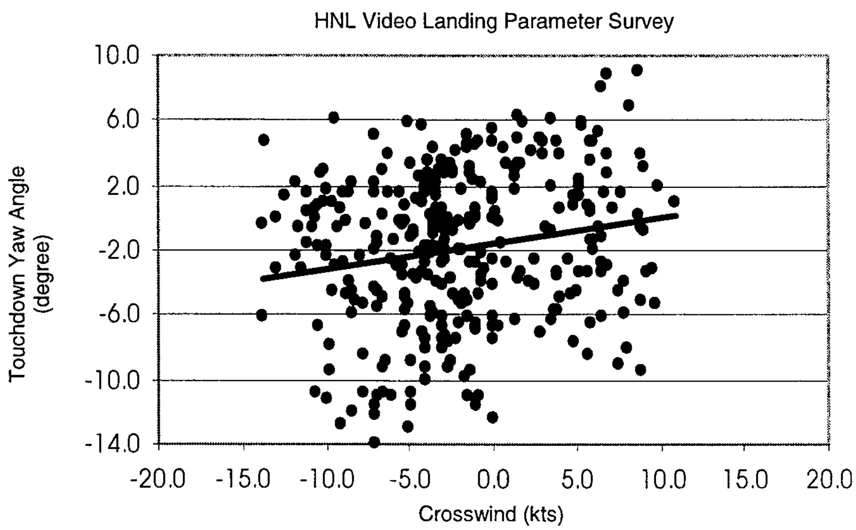

FIGURE 12. TOUCHDOWN YAW ANGLE VS CROSSWIND

3.4 COMPARISON OF HONOLULU INTERNATIONAL AIRPORT RESULTS WITH JOHN F. KENNEDY INTERNATIONAL AIRPORT RESULTS.

As was mentioned in the introduction, the primary purpose for conducting the Honolulu video landing parameter survey was to obtain a significant quantity of heavy, wide-body landings to compare to the unexpectedly high sink rates for heavy, wide-body landings observed during the JFK survey in 1994. Table 7 presents a direct comparison of the results obtained from the HNL survey and the previous results obtained at JFK.

The number of aircraft models available for direct comparison is somewhat limited since the survey at DCA did not include any wide-body jets, which were one of the primary areas of interest for the JFK survey. In addition, no A-320 landings were recorded at JFK. This left five narrow-body jet models for comparison, although the number of Boeing 737 aircraft recorded at JFK was extremely small. The sample size for any one model type is not sufficient to conduct any meaningful comparison or draw conclusions regarding the sink rate and approach velocity of each aircraft model. The apparent differences in mean values and standard deviation of table 2 may result from the difference in runway length (9000 ft at JFK, 7000 ft at DCA) and approach patterns at the two airports.

TABLE 7. COMPARISON OF LANDING SURVEY RESULTS (HNL VS JFK)

Aircraft Model		HNL Survey 1996		JFK Survey 1994	
		Approach Speed	Average Sink Speed	Approach Speed	Average Sink Speed
Boeing B-747	Mean	143.1(kts)	2.99 (fps)	145.6 (kts)	3.24 (fps)
	Standard Deviation	9.3	1.71	9.25	1.99
	No. of Landings	125	125	51	51
Boeing DC-10	Mean	153.5 (kts)	3.44 (fps)	142 (kts)	2.53 (fps)
	Standard Deviation	12.1	1.89	8.15	1.84
	No. of landings	148	148	12	12
Lockheed L-1011	Mean	154.2 (kts)	3.29 (fps)	142.4 (kts)	2.72 (fps)
	Standard Deviation	8.8	1.37	11.9	1.84
	No. of Landings	39	39	30	30

An unexpected number of high sink speed landings were observed during this survey. While aircraft sink speeds of 10 ft/sec are frequently observed during carrier operations, it was anticipated that landings in excess of 4 ft/sec would be rather rare in commercial operations. The results of this survey have identified 103 landings (almost 20%) which had sink speeds of 4 ft/sec or more and 3 landings were between 8 and 9 ft/sec. In comparison, 90 landings with sink speeds in excess of 4 ft/sec were measured during the JFK survey (15%). The JFK survey measured six landings in excess of 8.0 ft/sec, four narrow- and two wide-body jets. The design limit descent velocity for commercial transports is 10 ft/sec [14], and 14 Code of Federal Regulations (CFR) 25, Aeronautics and Space, Airworthiness Standards: Transport Category Airplanes considers this a once per lifetime event. The CFR does not specify a sink speed frequency distribution. The military specification MIL-A-8866 for similar aircraft assumes a 10-ft/sec landing occurs once every 2000 landings and a 9-ft/sec landing once every 1000 landings. Figure 5 provides a histogram of the sink speed distribution recorded during this survey.

Since there is no equivalent commercial specification, the observed sink speed distributions from the DCA and JFK surveys were compared with the distributions from MIL-A-8866. Commercial manufacturers estimate the anticipated usage of the aircraft during the airplanes design phase. Figure 7 is a plot of the probability that an aircraft's sink speed would reach a particular value. The military specifications are identified as the MIL-A-8866 curve. Separate curves are included for narrow-body aircraft from the DCA and JFK surveys.

3.5 COMPARISON WITH PRIOR NASA RESULTS.

The early NASA photographic landing surveys [3-6] were conducted in the late 1950s and early 1960s to determine whether a significant difference existed between the sink rates of narrow-body jet airplanes and piston engine transports. The studies determined that the jet airplanes did have sink speeds greater than the piston transports, however, since these values averaged well below 2 ft/sec, the continued use of a 10-ft/sec design value was considered to be appropriate.

The data collected at JFK, DCA, and now HNL show sink rates considerably greater than those from the prior NASA research. These new findings are of concern to both the FAA and industry. A joint FAA and Industry research team has been established to independently check system accuracy and determine the exact cause of these differences.

4. CONCLUDING REMARKS.

This research is part of a continuing series of landing parameter surveys intended to assess current design and regulatory requirements for aircraft landing gear and support structure. The video landing data acquisition system has been shown to be a practical, cost-effective technique for collecting large quantities of typical landing parameter data at a major commercial airport. Results of this survey are as follows.

- The survey results have been consistent, and comparable results have been found for similar aircraft models.
- The results from the large quantity of wide-body jet aircraft (B-747, DC-10, MD-11, and L-1011 models) collected in the HNL survey are consistent with the data on these aircraft previously reported from the JFK survey.
- The sink speed distributions resulting from the FAA surveys are greater than those found in previous NASA work. The volume and intensity of current flight operations may contribute to this variation.
- Due to the dispersion of landing parameters, an analysis of weather effects on landing parameters should be undertaken during subsequent surveys.
- Additional survey data are needed to properly assess current regulatory requirements.

5. REFERENCES.

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6. NASA TN-D-899, "An Investigation of Landing-Contact Conditions for Two Large Turbojet Transports and a Turboprop Transport During Routine Daylight Operations," 100 Landings (T-Prop), May 1961.

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10. Naval Air Warfare Center Aircraft Division, Warminster, PA, Technical Report 93004-60, "Naval Aircraft Approach and Landing Data Acquisition System NAALDAS Video Landing System Land Based Evaluation," 15 April 1993.

11. DOT/FAA/CT-93/7, "Methods for Experimentally Determining Commercial Jet Aircraft Landing Parameters From Video Image Data," August 1993.

12. DOT/FAA/AR-96/125, "Video Landing Parameter Survey—John F. Kennedy International Airport," July 1997.

13. DOT/FAA/AR-97/106, "Video Landing Parameter Survey—Washington National Airport," June 1999.

14. Title 14 Code of Federal Regulations Part 25, Aeronautics and Space, Airworthiness Standards: Transport Category Airplanes.

APPENDIX A—FAA VIDEO LANDING PARAMETER SURVEY— HNL INTERNATIONAL INDIVIDUAL LANDING LISTINGS

LANDING DATA MODEL BOEING 747AIRCRAFT
FAA SURVEY HONOLULU INTERNATIONAL AIRPORT

LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN PORT FPS	SINKING SPEED AT TOUCHDOWN STBD FPS	SINKING SPEED AT TOUCHDOWN AVG FPS	WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
2	153.8	154	0.6	4.2	1.3		1023	-6	1.3	6.5	-2.9	5.4	0	0
12	131.0	135	2.7	3.5	3.1	505500	2137	-6	1.0	5.8	-2.8	-0.2	-4	-1
20	144.4	147	0.0	1.4	0.7	497957	2750	-4	1.1	7.4	-2.4	0.5	-3	-3
24	139.0	141	0.0	3.6	1.8	491800	2192	-6	1.0	4.4	-0.6	-1.1	-2	-5
25	155.4	156	3.2	2.3	2.8	495000	1822	2	1.0	5.3	-1.1	2.7	-1	-3
26	149.1	153	2.1	3.0	2.6	493086	2633	-4	0.9	4.6	-1.5	4.2	-4	-4
32	147.2	144	7.7	7.2	7.4	511200	1918	0	0.6	3.5	-1.8	1.6	3	0
37	128.8	127	-0.2	3.9	1.8	496200	2299	-5	1.1	3.6	-1.3	-3.9	2	-1
39	151.8	145	5.8	5.3	6.2	516200	2230	-2	0.9	3.8	-0.4	-0.7	7	-2
51	127.8	118	3.1	2.7	2.9	492100	1969	-6	1.0	4.0	-1.4	3.4	10	1
64	156.5	144	0.6	-0.6	0.0	533066	2258	-13	1.3	4.2	-2.6	-3.9	13	2
69	148.8	142	3.6	-0.7	1.5	475000	2094	-6	1.3	5.9	-3.2	-2.0	7	-7
99	158.0	154	3.4	4.1	4.2	516849	1171	1	1.1	8.5	-6.1	0.8	4	-10
155	148.4	142	5.0	2.9	4.0	507466	1692	-3	0.9	8.9	-0.3	2.8	6	-10
178	144.2	138	6.5	3.1	4.8	475100	1811	-6	1.0	3.7	-3.9	-10.9	6	-8
179	147.6	141	0.4	4.0	2.2	490596	3260	-10	0.9	6.4	-1.4	-14.0	7	-7
180	142.9	136	5.8	2.4	4.1		1768	4	1.0	3.8	-3.2	-11.6	7	-7
181	148.0	142	2.5	3.3	2.9		3250	-10	0.8	6.9	-2.0	-11.1	6	-7
190	123.8	115	-1.0	1.1	0.1	440000	1714	2	1.5	3.6	-2.0	5.7	9	-4
193	140.6	134	3.5	3.1	2.8	462000	2431	-22	0.9	5.0	-2.4	-7.9	7	-10
195	143.8	137	-0.1	1.6	0.8	497370	3293	-17	1.0	8.1	-3.0	-9.4	7	-10
197	138.4	131	2.0	2.0	2.0	502500	2992	-9	1.1	5.5	-1.9	-4.5	7	-8
199	149.6	138	4.3	2.7	3.5	484556	1876	-13	1.1	6.4	-1.7	-9.2	11	-7
203	168.3	157	6.9	4.1	5.5	491000	1914	-1	0.7	3.6	-3.4	1.8	11	-4
204	147.6	137	2.2	4.9	3.6	476800	1789	-7	1.0	4.7	-3.3	-11.1	10	-6
209	136.1	125	3.7	4.3	4.0	468200	1792	-3	0.9	4.5	-2.0	-12.9	11	-9
221	147.9	138	4.0	1.4	2.7	494100	1857	-9	1.0	2.9	-5.2	-11.3	10	-10
235	152.4	144	6.4	8.1	7.2	473800	889	-12	1.3	5.7	-2.4	1.8	8	-10
257	140.8	139	5.7	3.5	4.6	506680	1594	-2	1.0	7.1	-5.1	-1.9	2	-10
259	151.3	144	0.1	2.9	1.5		754	-12	1.0	7.3	-2.6	-3.0	7	-6
284	134.6	129	5.2	3.3	4.2	524700	1656	-13	1.1	8.2	-3.4	-5.2	6	-8
307	156.3	147	2.5	4.7	4.1		1232	2	1.1	10.7	-6.8	3.4	9	2
332	152.2	142	0.9	4.3	2.9	498500	2072	9	1.1	9.7	-1.4	1.6	10	-11
335	151.2	145	4.8	2.9	3.9	516000	1695	-2	0.9	8.6	-3.0	6.1	6	-9
339	134.3	122	2.6	1.4	2.0	434600	1652	-6	1.0	3.7	-3.9	-4.0	13	-3
341	143.7	137	3.1	4.5	3.8		3049	-3	0.9	3.9	-0.1	-2.2	7	-1
349	149.6	141	4.1	0.9	2.5	488000	2995	-7	1.0	7.4	-1.2	-4.1	9	0
351	136.3	127	4.2	2.6	3.4	479660	571	-6	1.3	6.6	-0.8	4.2	9	-2

LANDING DATA MODEL BOEING 747AIRCRAFT
FAA SURVEY HONOLULU INTERNATIONAL AIRPORT

LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN PORT FPS	SINKING SPEED AT TOUCHDOWN STBD FPS	SINKING SPEED AT TOUCHDOWN AVG FPS	WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
352	152.4	144	4.5	5.4	5.0		1696	-3	0.9	5.9	-3.8	-7.6	8	-3
356	140.3	127	5.5	5.4	5.5	472000	1343	4	0.9	3.6	-3.0	2.3	13	-1
358	154.2	146	8.5	6.0	7.3	530000	926	-5	1.1	6.4	0.4	-2.8	8	-3
361	150.2	139	8.0	3.6	5.8	489500	1681	2	0.9	5.9	-3.4	-6.2	11	0
364	138.4	126	2.5	0.0	1.2	482400	1959	3	1.3	6.5	-3.1	5.1	12	-7
367	141.9	130	3.1	2.9	3.0	476900	1768	-7	1.1	6.2	-3.2	-6.5	12	-2
370	118.5	111	2.4	1.2	1.8	423288	1581	-13	1.1	5.9	-4.6	-3.8	8	-5
375	147.5	137	3.2	1.7	2.5	498400	1264	-3	1.2	3.7	-5.3	-0.5	11	-8
382	150.2	145	4.7	4.6	4.7		905	-11	1.0	6.7	-1.1	-1.4	5	-6
396	133.8	129	2.1	4.7	3.4	420000	2052	-3	0.9	3.8	-3.2	-0.5	5	-3
414	157.5	147	3.1	-1.7	0.7	519339	2881	4	1.1	6.1	-1.4	-0.4	11	-1
425	148.7	137	-0.1	3.9	1.9	508152	1538	4	1.2	5.7	-3.0	-1.8	11	-4
488	143.2	131	1.6	1.8	1.7		2762	4	1.0	8.9	0.1	3.4	12	2
497	134.0	126	-0.1	2.5	1.2	488298	2008	-2	1.2	5.0	-1.8	1.2	8	0
499	146.3	140	3.8	2.5	3.2	490700	2318	-1	0.9	5.2	-2.5	-5.9	6	-4
502	134.2	126	5.8	4.3	5.0		1302	2	1.2	5.4	-4.3	1.7	8	1
505	134.0	129	3.5	1.5	2.5	482001	2181	-2	1.0	5.7	-3.8	-2.6	5	0
509	144.8	138	1.9	4.6	2.9	500000	1392	-9	1.0	7.4	-3.9	-2.6	7	0
519	145.5	140	3.7	1.2	2.5	494700	2261	5	0.9	4.6	-0.2	-2.8	6	-1
522	148.7	140	3.1	-0.1	1.5	481676	1863	2	1.1	2.5	-2.5	4.6	9	-1
523	139.5	133	0.7	3.7	2.2	401150	1757	-5	1.1	5.7	-1.7	2.0	7	-4
528	141.6	135	-2.0	2.5	0.3	500403	1892	0	1.4	5.7	-1.4	2.2	7	-1
533	149.4	141	3.2	3.4	3.3	504004	2041	4	1.1	5.0	-2.1	3.0	9	-2
534	155.8	145	1.7	2.1	1.9		1954	-6	0.9	8.9	-0.1	5.9	11	-5
543	153.5	147	2.9	2.1	2.5	509000	2360	-6	1.1	3.9	-2.9	-5.3	6	-8
554	140.8	131	1.6	4.9	3.3	484996	1999	-9	1.2	4.1	-0.4	0.4	10	0
556	147.1	134	0.6	2.1	1.3	525000	1605	-6	1.2	5.3	-4.0	-3.5	13	-1
560	140.2	129	2.6	-1.7	0.5	525691	1905	-2	1.1	6.4	-1.4	0.2	11	-1
582	144.2	126	2.8	1.4	2.1	518294	2882	-9	1.1	8.3	-1.1	-1.3	18	-5
583	147.7	134	2.3	3.7	3.0	620000	3153	-1	1.0	8.7	-0.5	-6.8	14	0
588	144.5	126	4.4	4.5	4.4	519799	1730	-3	0.8	9.3	-3.7	-5.2	19	-2
616	129.7	118	4.0	-0.1	1.9		2413	6	1.1	7.8	-3.0	4.6	12	-14
668	154.7	156	3.1	2.7	2.9	505000	2375	-5	1.1	6.6	-1.5	-6.2	-1	-2
677	135.9	140	-0.8	4.9	2.1	514200	2010	-3	1.1	5.1	-0.8	-1.4	-4	-3
678	136.1	141	1.6	-1.6	0.0	492000	2500	2	1.3	5.8	-2.0	2.8	-5	-4
679	141.9	147	-0.3	1.8	0.8	500392	1726	1	1.0	5.1	-0.8	1.8	-5	-4
686	156.6	155	3.8	7.0	5.4	490065	1474	-11	0.9	4.6	-3.9	-2.6	2	3
687	132.1	133	-2.3	6.4	2.1	467400	1976	-3	1.1	4.3	-1.3	3.4	-1	-5

LANDING DATA MODEL BOEING 747AIRCRAFT
FAA SURVEY HONOLULU INTERNATIONAL AIRPORT

LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN PORT FPS	SINKING SPEED AT TOUCHDOWN STBD FPS	SINKING SPEED AT TOUCHDOWN AVG FPS	WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
690	147.6	149	7.3	6.6	6.9	498100	1713	-1	0.9	4.7	-2.2	-6.2	-1	-4
714	126.8	123	-1.6	4.3	1.4	485300	1780	-4	1.2	4.4	-1.1	3.0	4	1
736	142.3	141	4.1	1.8	3.0	518262	1811	2	1.0	6.5	-1.0	-9.5	1	9
739	141.4	139	5.6	-0.4	2.6	507354	2144	-2	1.1	8.1	-0.2	1.6	2	8
822	142.0	143	0.2	0.7	0.5	464346	2467	-5	1.1	7.6	-4.2	-9.2	-1	-3
824	135.1	134	2.2	0.7	1.4	436700	2422	-10	1.1	5.5	-3.0	-5.3	1	-2
825	143.8	141	1.8	1.8	1.8		1812	-23	1.1	4.7	-3.9	-6.6	3	-1
826	134.3	136	2.9	3.5	3.2	508000	1758	-7	0.9	7.0	-4.3	3.4	-2	-3
830	146.0	147	5.2	0.7	2.9	468427	1515	-3	1.0	5.1	-4.0	3.0	-1	-3
835	133.1	135	0.2	4.6	2.4	463400	2017	-1	1.1	4.1	-3.3	-2.2	-2	-4
839	144.1	146	3.1	0.1	1.6	491000	1674	-8	1.2	6.8	-3.2	-5.5	-1	-4
842	150.3	151	0.8	7.5	7.0	487416	2586	2	0.9	5.3	-0.5	-0.2	-1	-3
847	142.3	143	2.8	4.3	3.5	455800	1720	-16	0.9	5.9	-2.9	-6.9	0	-1
855	154.1	157	5.7	5.2	5.4	487400	2314	0	0.8	3.5	-3.8	-1.6	-3	1
863	138.9	141	0.7	5.4	3.1	415800	1017	0	1.2	4.8	-0.1	-4.1	-2	2
871	136.0	138	1.4	2.3	3.0	453100	1887	1	1.0	4.4	-1.1	0.8	-2	6
880	158.0	160	0.2	1.7	1.0		1277	-7	1.3	7.0	-4.9	0.1	-2	-4
882	142.8	143	4.3	5.7	5.0	477000	1838	-12	0.9	7.2	-2.8	-11.7	0	-1
890	140.8	139	3.1	1.5	2.3	457394	1612	-7	1.0	6.6	-4.5	-2.7	1	-1
891	138.2	139	2.5	2.6	2.5	456300	2197	-6	1.0	5.3	-3.6	-0.7	-1	-3
893	137.0	138	2.6	-0.3	1.1	457204	2447	-5	1.0	6.6	-1.6	5.0	-1	-2
897	137.2	136	2.6	0.9	1.8	455000	2234	-7	1.0	5.0	-2.8	-2.0	1	-2
899	142.2	142	4.8	5.3	5.0	504600	1792	7	1.0	5.9	-1.3	4.5	0	-1
902	128.9	125	5.7	5.2	5.4	414600	2841	6	0.9	5.7	-1.3	2.6	4	1
922	140.8	143	6.1	7.8	7.0	454000	1983	1	1.0	4.4	-2.8	1.9	-2	4
945	166.8	169	0.4	0.9	0.6		2235	-2	1.2	7.6	-4.2	-3.3	-2	6
947	157.1	160	1.5	2.4	2.0	511422	1631	-14	1.0	6.9	-4.1	5.6	-3	5
980	132.3	130	1.5	1.2	1.4		1486	4	1.4	9.6	-2.9	10.4	2	7
1002	150.6	150	-0.6	2.0	0.7	505123	2210	-1	1.2	7.8	0.0	-1.5	1	6
1028	118.2	119	3.4	5.3	4.4	481400	2748	5	0.8	6.3	-1.8	4.0	0	3
1030	138.3	140	4.4	2.9	3.6	510000	3110	2	0.9	5.9	-0.1	-5.8	-1	4
1052	127.4	128	4.2	1.4	2.8	413600	1529	-8	1.0	3.4	-4.8	0.0	0	-1
1054	134.4	135	-0.2	1.2	0.5	439200	3028	-3	1.1	6.4	0.1	-3.6	-1	-1
1058	152.9	154	5.4	4.8	5.1	448000	1304	-5	1.1	5.2	-3.9	1.7	-1	-2
1061	136.0	138	2.6	5.1	3.9	448117	2677	2	0.9	6.4	-1.7	-0.3	-2	-3
1070	135.1	134	4.7	1.4	3.1		1864	2	1.1	6.4	-1.9	4.3	1	1
1082	143.9	145	4.4	4.5	4.5	448000	1676	-1	1.0	6.5	-3.2	-7.7	-1	-3
1084	140.0	142	6.2	1.4	3.8	441000	1753	-11	0.9	3.9	-4.1	-8.8	-2	-3
1086	161.0	161	3.2	3.3	3.3		3170	-11	1.0	6.5	0.5	-9.2	0	-4

LANDING DATA MODEL BOEING 747AIRCRAFT
FAA SURVEY HONOLULU INTERNATIONAL AIRPORT

LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN PORT FPS	SINKING SPEED AT TOUCHDOWN STBD FPS	SINKING SPEED AT TOUCHDOWN AVG FPS	WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
1092	135.4	139	1.8	2.6	2.2	444000	1556	-8	1.1	5.3	-2.7	-3.5	-3	-4
1093	127.6	132	3.7	5.0	4.4	469300	2577	-1	0.8	4.9	-0.5	1.5	-4	-6
1099	125.3	125	1.3	3.1	2.2	467078	2773	8	1.1	7.5	-1.7	-1.9	0	-3
1101	132.9	135	2.5	5.9	4.2	463456	1441	-8	0.9	7.0	-3.1	-1.8	-2	-3
1105	145.8	147	4.1	3.5	3.8	484300	1784	-2	0.9	3.1	-3.1	-11.1	-1	-2
1114	141.8	139	-0.9	4.3	1.7	476800	2493	1	1.0	6.0	0.9	4.4	3	-2
1118	145.2	142	0.0	1.0	0.5	497100	2175	2	1.1	5.2	0.9	6.1	4	4
1130	140.0	141	4.9	1.6	3.2	457300	2530	9	1.0	4.4	1.0	4.7	-1	6
1198	155.6	151	5.7	5.3	5.5		1560	-24	1.0	8.8	-2.2	0.1	5	9
1212	144.4	144	1.0	6.8	3.9		1358	1	1.2	6.8	-4.1	-0.9	0	9

LANDING DATA MODEL BOEING 767AIRCRAFT
FAA SURVEY HONOLULU INTERNATIONAL AIRPORT

LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN			WEIGHT	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
			PORT FPS	STBD FPS	AVG FPS	LBS								
59	143.2	134.2	4.75	5.04	4.90		1633	-7	0.9	5	-2.8	-4.8	8.96575	-0.78440
101	155.6	147.6	1.89	4.66	3.92		1114	-5	1.1	8.4	-7	1.6	8.02957	-8.91774
220	151.9	135.4	1.45	3.20	2.33		1501	-7	1	4.8	-4.2	0.9	16.45448	-9.50000
383	137.5	129.8	2.46	3.01	2.73		1607	-9	0.9	5.3	-3.8	-4.8	7.65044	-2.33897
422	141.4	131.6	0.88	5.12	3.00		2556	1	1.2	7.7	-0.3	-1.3	9.82982	-6.88292
572	152.5	133.2	4.60	6.10	5.35	273370	1153	-18	1	7.5	-4.1	0.8	19.31852	-5.17638
578	129.4	117.6	3.44	3.42	3.43		1600	-5	0.9	4.4	-3.7	-5.1	11.81769	-2.08378
707	137.5	134.1	4.63	2.99	3.81		1745	-9	0.9	3.4	-2.8	-10.8	3.44146	-4.91491
867	152.9	153.5	3.49	3.09	3.70		2377	-9	0.9	5.9	-1.3	-2.9	-0.61009	6.97336
1021	157.1	153.5	2.44	4.60	3.52	270000	1748	-7	0.9	4.1	-3.6	-9.8	3.62523	-1.69047
1119	154.3	152.3	4.08	5.36	4.72	246935	1658	-1	0.9	2.9	-0.3	-6.8	1.96962	0.34730

LANDING DATA MODEL DOUGLAS DC-10 AIRCRAFT
FAA SURVEY HONOLULU INTERNATIONAL AIRPORT

LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN			WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
			PORT FPS	STBD FPS	AVG FPS									
5	157.9	161.4	0.3	0.8	0.5	317900	1457	0	1.1	7.5	-3.2	-5	-3.5	-2.0
19	141.9	144.5	0.8	2.4	1.6	324000	2630	-7	1.1	6.7	-0.6	3.6	-2.6	-3.1
21	128.2	129.7	1.9	3.1	2.5	333900	2480	4	0.8	6.8	-0.4	2.8	-1.5	-1.3
66	166.8	158.1	3.6	5.3	4.5	0	1344	-6	1.1	6.9	-0.1	2.7	8.7	-2.3
90	158.7	148.9	1.5	3.9	2.7	323000	905	-8	1.1	10.2	0.0	-3.4	9.8	1.7
94	159.5	155.0	2.3	3.6	2.9	394000	1571	-1	1.1	7.1	-4.2	-3.5	4.5	-5.4
100	144.6	138.6	4.9	9.6	7.2	334600	988	-5	1.1	9.3	-3.4	-1.8	6.0	-10.4
105	174.6	167.1	8.9	3.9	7.0	341100	2346	-6	0.8	7.7	-5.9	-4.9	7.5	-6.6
113	139.5	134.8	3.7	3.7	3.7	331600	2211	-6	1.0	9.2	-3.3	-2.8	4.7	-8.8
123	166.4	157.4	4.6	5.5	4.2	411000	1279	0	1.0	12.2	-6.3	-0.6	9.0	-10.7
132	152.3	144.3	4.2	3.6	3.9	0	2209	-9	1.1	9.5	-4.0	-6.2	8.0	-13.9
134	162.8	155.4	2.8	4.2	3.5	383400	1260	-7	1.2	8.9	-3.9	-2.9	7.4	-9.5
135	174.9	165.7	2.3	1.0	1.6	378800	774	4	1.2	9.1	-0.6	0	9.2	-10.6
153	154.9	144.7	5.1	3.7	3.8	337300	1502	-1	1.1	9.0	-6.9	-4.5	10.2	-9.5
169	153.5	138.6	5.0	5.1	5.4	334900	1271	0	1.1	12.9	-5.6	1	14.9	-10.1
171	161.5	149.1	2.0	2.4	2.2	373000	1930	-7	1.0	5.0	-2.8	-0.7	12.4	-11.6
172	146.8	139.3	6.7	9.1	7.9	375000	658	0	1.0	10.5	-1.3	0.6	7.5	-10.6
174	152.0	142.0	-0.6	3.5	1.5	373000	1368	-3	1.0	10.8	-4.4	-1.7	10.0	-11.1
185	163.2	157.1	3.2	3.1	3.2	358700	1606	-10	1.1	6.6	-4.5	-4.9	6.1	-5.1
189	164.4	155.0	4.8	4.1	4.4	338000	1215	-1	1.0	6.2	-4.3	0.6	9.4	-3.4
192	136.0	128.7	0.4	2.8	1.6	366202	2699	-3	1.1	4.8	-0.7	0.2	7.3	-3.4
194	147.4	141.1	1.9	2.2	2.6	319000	1947	-12	0.9	7.4	-2.3	0.5	6.3	-9.0
202	134.0	128.0	2.1	4.2	3.1	328700	2289	-15	1.2	5.9	-1.8	-6.7	6.0	-10.4
234	159.0	153.5	0.3	3.7	2.0	372000	2091	5	1.0	6.9	-1.1	-2.3	5.5	-11.8
249	174.1	165.7	2.8	5.4	3.4	0	1154	-5	1.0	9.0	-6.3	1.6	8.4	-7.1
251	146.7	141.7	0.7	1.8	3.1	375000	797	-1	1.2	8.2	-1.3	-0.3	5.0	-8.7
256	149.9	145.9	4.8	4.5	5.2	333600	1489	-7	1.0	10.5	-3.4	-4.6	4.0	-6.9
267	160.3	153.2	1.3	2.3	1.8	333400	1864	-10	1.1	7.1	-4.9	-12.2	7.1	-7.1
268	169.2	165.0	5.1	8.4	6.7	331700	1347	3	1.1	9.7	-3.5	-3.3	4.2	-4.2
282	149.5	143.0	1.9	5.4	3.7	332400	1978	-6	1.0	8.3	-2.2	3	6.5	-10.1
283	167.1	162.5	4.8	5.8	5.3	366000	1813	-9	0.9	8.0	-4.1	-10.8	4.6	-6.6
291	141.8	138.6	3.2	2.5	2.8	372300	1134	-9	1.0	13.2	-0.9	-12.1	3.2	-8.4
296	159.2	152.6	1.2	-0.6	0.3	367200	1880	-11	1.2	10.0	-2.4	1.3	6.6	-12.4
308	149.3	143.7	5.9	3.2	4.1	342000	1549	-3	1.1	10.5	-6.9	-2	5.6	-2.1
311	146.8	140.8	5.6	7.1	7.4	346000	762	-7	1.1	9.3	-1.8	-0.6	6.0	-9.2
324	142.0	127.8	4.4	6.4	5.9	338500	2017	-8	1.1	10.9	-5.0	0.4	14.2	-11.1
326	171.4	164.9	3.1	2.0	3.2	377000	1753	9	1.1	8.2	-1.7	4	6.5	-6.3
330	127.8	117.0	4.0	7.7	5.8	332500	2018	-11	0.9	11.4	-2.8	-0.9	10.8	-2.3

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LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN PORT FPS	STBD FPS	AVG FPS	WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
334	151.0	144.9	3.3	6.4	4.8	336000	1225	-7	1.1	6.8	-5.6	-3.1	6.1	-11.5
336	139.7	126.7	3.2	7.2	5.9	365000	1047	-2	1.0	11.0	-1.9	-0.2	13.0	-5.2
342	142.9	134.0	2.1	2.0	2.1	429000	1501	-9	1.0	9.1	-3.5	-3.8	8.9	1.6
350	150.0	141.5	0.5	1.0	0.8	343500	1662	3	1.1	7.9	-4.4	-6.2	8.5	-3.1
355	147.5	135.5	2.9	0.6	1.8	316600	2467	-7	1.0	7.4	-2.2	-11.2	12.0	-1.0
357	164.4	156.9	3.9	1.4	2.7	372780	1860	-8	1.1	5.5	-3.8	-16.2	7.5	-2.7
390	150.3	136.9	4.4	5.0	4.7	367000	1597	-8	1.1	7.9	-4.0	-5.6	13.4	-6.8
411	149.5	139.5	0.6	4.4	2.5	367000	2588	-8	1.1	9.9	0.3	-0.5	10.0	-13.8
412	148.5	135.8	4.5	5.1	4.8	320800	1381	-4	0.9	7.5	-3.3	-2.4	12.7	-7.9
421	154.0	143.8	3.5	1.2	2.3	332800	2130	-5	1.0	8.9	-1.1	1	10.2	-4.1
428	143.0	133.6	-0.1	3.4	1.6	337500	2531	1	1.1	9.9	0.1	2.1	9.4	-3.4
429	135.8	125.3	2.8	2.6	2.7	326300	1660	3	1.0	13.3	-3.7	3	10.5	-3.2
430	156.9	150.0	2.2	3.2	2.7	0	2007	7	1.1	10.0	-1.3	1.5	6.9	-4.0
437	152.1	135.2	1.8	4.9	3.3	334800	2615	2	1.0	7.1	-0.3	1.6	16.9	-6.2
443	150.3	137.1	2.9	2.4	3.0	369000	1627	-5	1.1	8.7	-4.7	-3.6	13.2	-4.8
445	157.1	145.8	3.9	1.9	2.9	0	1556	-6	1.1	8.8	-4.5	-2.7	11.3	-4.1
468	153.5	143.0	2.7	4.6	3.6	363300	922	-5	1.2	10.5	-3.5	2.8	10.5	-3.2
472	167.5	160.3	5.5	7.4	6.5	372000	859	-12	1.2	9.3	-5.5	-1.7	7.2	-6.9
476	126.5	111.6	3.9	6.5	5.2	368500	1076	-4	1.0	9.5	-1.7	0	14.9	-1.3
489	145.1	139.6	0.5	2.3	1.1	370000	1243	4	1.2	8.0	-5.3	2.5	5.5	-4.3
490	168.0	160.6	5.7	8.2	7.0	0	1635	-13	1.1	8.3	-4.0	-6.7	7.4	-5.2
491	123.1	114.7	0.4	1.8	2.2	337100	1685	1	1.2	7.9	-1.0	2.2	8.4	-7.1
492	162.7	151.4	3.4	3.9	3.6	376000	1664	-4	1.0	3.5	-4.2	-7.6	11.3	-4.1
494	160.0	155.2	3.6	2.4	3.0	0	1802	-6	1.0	5.4	-4.1	-9.5	4.8	-1.3
510	137.8	131.9	0.7	2.1	1.4	359799	1303	-2	1.1	6.3	-3.7	0.6	5.9	-1.0
513	151.3	142.4	1.1	2.3	1.7	348600	2470	5	1.0	8.1	-1.3	4.8	8.9	1.6
514	142.4	137.5	0.5	-0.7	0.0	375151	1966	-1	1.5	7.6	-1.8	1.6	4.9	-3.4
552	162.2	147.8	2.7	3.4	3.0	314000	1687	3	1.0	7.3	-2.9	-7.2	14.4	-4.1
574	153.3	140.5	3.8	5.4	4.6	362000	1609	-8	1.1	11.5	-1.9	4.1	12.8	-2.3
580	161.2	147.1	0.9	2.4	1.6	337600	1077	-2	1.0	8.2	-1.0	-5.7	14.1	-5.1
587	161.9	143.5	3.0	3.8	3.4	330800	1857	-12	1.0	8.3	-3.9	-11.7	18.4	-4.9
592	159.0	147.0	3.9	1.6	2.8		1128	-5	1.0	11.0	-0.5	-7.6	12.0	0.0
593	165.6	148.6	0.8	4.1	2.5	339500	1488	-1	1.1	8.2	-2.8	-0.1	17.0	0.0
599	176.8	161.9	6.0	0.9	2.4	333100	2236	0	1.0	7.3	0.9	-6.4	14.9	1.3
603	157.4	139.5	4.8	2.9	3.9	335300	1432	3	1.0	8.2	-3.5	-5.1	17.9	-1.6
608	162.3	147.3	2.2	3.2	2.7	369200	3273	-12	1.0	8.4	-1.6	-12.5	15.0	0.0
613	118.7	107.4	2.0	1.2	1.6	372000	2281	4	1.1	10.1	-1.4	3	11.3	-6.5
614	169.3	160.6	3.4	4.3	4.5	0	1729	-1	0.9	7.2	-3.5	-5.3	8.7	-5.0

LANDING DATA MODEL DOUGLAS DC-10 AIRCRAFT
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LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN PORT FPS	SINKING SPEED AT TOUCHDOWN STBD FPS	SINKING SPEED AT TOUCHDOWN AVG FPS	WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
626	164.2	152.5	1.5	2.5	2.0	351800	2046	-2	1.2	9.0	-2.8	-3.7	11.7	-2.5
646	164.3	154.3	0.7	4.2	2.5	374000	510	-1	1.1	10.4	-1.8	2.2	10.0	-8.4
648	170.6	158.3	3.7	1.5	2.6	380000	2753	-2	1.0	5.7	-1.7	-4	12.3	-8.6
649	155.5	146.1	3.7	6.2	5.0	340400	2604	-8	0.9	9.0	-0.3	1.4	9.4	-3.4
664	166.5	167.3	4.2	3.2	3.7	0	844	0	1.3	7.8	-0.8	-3.2	-0.8	-0.6
669	134.0	136.0	2.0	2.0	2.0	349000	2635	0	1.0	6.9	-1.0	-0.6	-2.0	-3.5
675	146.2	146.9	1.8	2.8	3.4	350800	2629	-5	0.9	7.6	-2.0	2.6	-0.7	-3.9
715	152.0	148.2	-0.6	5.0	2.2	355000	1027	10	1.5	8.4	-2.6	6.8	3.8	8.2
735	177.3	177.5	1.2	2.4	1.8	323400	1875	9	1.1	10.1	-1.4	3.2	-0.2	9.0
737	140.8	137.1	3.2	3.4	2.1	0	1520	2	1.0	9.0	-4.5	0.5	3.7	5.9
741	147.4	142.8	2.8	3.5	2.2	380000	1560	9	1.2	8.5	-2.0	-3.3	4.6	6.6
749	144.2	141.8	3.2	5.2	3.7	334400	939	13	1.0	9.0	3.0	-6.2	2.4	6.6
753	156.1	154.5	5.5	5.9	5.7	0	811	-2	1.0	9.0	0.6	-0.7	1.6	8.9
765	149.9	150.9	3.1	-1.9	0.6	341400	1114	-2	1.0	12.4	0.9	-7.2	-1.0	2.8
772	155.1	158.9	6.9	5.1	6.0	0	1355	3	1.1	9.8	-3.5	-0.7	-3.8	3.2
773	170.4	164.0	1.1	3.0	3.9	0	846	-4	1.2	12.4	3.0	-0.6	6.4	6.4
785	159.2	164.3	6.1	3.0	4.6	0	1460	-3	1.0	6.9	-3.1	-2	-5.1	6.1
800	166.0	169.7	6.0	3.4	4.7	0	1494	-9	1.0	8.7	0.3	-4.8	-3.7	4.7
804	165.8	171.9	4.6	-0.9	3.6	342192	919	-6	1.2	10.7	-0.6	-3.4	-6.1	5.1
808	154.1	159.0	1.9	2.1	2.2	374000	2092	4	1.0	11.9	-1.9	1.4	-4.9	4.9
812	145.8	149.2	4.8	4.5	4.5	374000	1296	4	1.2	9.0	-1.5	0.5	-3.4	7.3
817	151.4	153.0	2.7	2.6	2.6	375000	1787	7	1.1	13.7	-2.7	-8.5	-1.6	5.8
823	161.3	161.3	1.3	1.4	1.3	335200	1864	-1	1.0	8.0	-4.1	0	0.0	-3.0
828	141.4	142.2	1.7	4.5	3.1	350900	1980	-1	0.9	7.7	-4.2	-0.8	-0.8	-2.9
829	146.3	146.0	1.6	1.3	1.4	331500	1604	3	1.0	7.2	-3.2	-4.2	0.3	-3.0
836	157.1	157.9	5.5	4.1	4.8	327100	2991	-14	1.0	8.0	-1.0	-2	-0.8	-2.9
837	166.2	167.5	0.8	-0.3	0.3	352587	2126	-4	1.1	7.2	-4.2	-0.1	-1.3	-2.7
884	171.1	171.1	1.5	1.9	1.7	330000	2132	-2	1.1	4.9	-3.9	-1.8	0.0	-3.0
887	148.7	149.7	2.4	1.6	2.0	322135	2443	-6	1.0	7.6	-4.1	-7.3	-1.0	-2.8
889	166.3	169.6	2.8	2.3	2.6	341000	2479	0	1.0	10.4	-1.4	4.1	-3.3	2.3
930	133.6	134.4	2.5	4.2	3.4	362500	2387	10	1.1	9.9	-1.4	5.8	-0.8	1.8
942	139.7	142.7	3.0	5.4	4.2	319800	1348	0	1.0	8.6	-3.3	-0.2	-3.0	0.3
949	136.3	137.6	0.5	-0.4	0.0	338900	1397	11	1.2	7.4	-4.1	6.3	-1.3	1.5
950	168.2	166.9	8.3	6.5	7.4	373000	1124	-3	0.9	9.2	0.7	-7.7	1.3	4.8
957	134.9	134.8	1.5	3.5	0.9	338800	1781	5	1.0	7.1	-7.6	3.9	0.1	4.0
960	137.9	138.6	7.8	7.8	7.8	338700	1011	13	1.0	9.3	-3.5	4.9	-0.7	2.9
974	179.4	176.8	4.0	-0.7	1.7	336800	1698	3	1.7	9.7	-1.1	4.7	2.6	3.1
979	156.7	159.7	-0.3	0.7	0.2	375212	2792	8	1.1	8.5	-2.0	1.9	-3.0	5.2

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LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN PORT FPS	SINKING SPEED AT TOUCHDOWN STBD FPS	SINKING SPEED AT TOUCHDOWN AVG FPS	WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
1001	148.8	147.8	6.0	3.7	4.8	378200	3062	6	0.9	8.6	-0.7	-3.3	1.0	3.9
1011	139.6	142.3	1.7	1.4	1.5	335400	1588	1	1.0	9.2	-2.8	-4.5	-2.7	7.5
1014	169.3	172.1	3.8	5.4	4.6	371500	1828	0	1.0	8.9	-3.4	5.6	-2.8	5.3
1015	159.7	156.7	3.5	3.2	3.4	382800	1961	3	0.9	8.2	-1.8	1.3	3.0	5.2
1016	148.0	150.4	6.1	5.7	5.9	333678	1734	2	0.8	10.4	-3.6	-5.3	-2.4	9.7
1017	162.7	161.8	4.6	3.5	4.0	373000	2133	4	1.0	8.1	-2.4	0.3	0.9	5.9
1018	140.8	141.4	7.3	4.0	5.6	331600	1542	-5	0.8	10.5	-4.2	0.5	-0.6	4.0
1020	157.6	158.0	3.9	1.8	2.5	375000	2272	2	1.0	9.7	-2.0	-4.6	-0.4	5.0
1041	165.6	168.6	3.2	-0.2	1.5	346627	2054	6	1.0	6.4	-3.0	1.4	-3.0	0.0
1048	156.0	156.5	5.3	4.8	5.1	345000	1708	-7	1.0	5.5	-4.1	-6.8	-0.5	-3.0
1050	140.8	140.6	2.0	2.0	2.0	322000	2631	-1	1.1	7.5	-1.2	-0.2	0.2	-2.0
1056	139.8	139.8	3.2	4.1	3.7	319641	1747	2	0.9	7.0	-1.4	-6.7	0.0	-1.0
1064	163.3	165.3	2.8	2.5	2.7	335000	2629	1	1.0	7.4	-1.1	-1	-2.0	-3.5
1073	149.3	151.7	6.7	6.9	6.2	333700	1579	9	0.9	9.5	1.4	-2.8	-2.4	6.6
1078	163.7	168.2	3.8	7.4	5.6	331100	1908	2	1.0	8.0	-4.2	5.8	-4.5	5.4
1081	154.1	156.6	3.1	3.1	3.1	359800	1691	-11	1.0	8.5	-3.2	-7.1	-2.5	-5.4
1083	155.2	152.3	2.9	1.0	2.0	336900	1789	-8	1.1	6.9	-4.1	-10	2.9	-4.1
1095	153.0	156.2	1.5	1.4	1.4	298400	2277	-8	1.0	7.5	-2.4	3.6	-3.2	-3.8
1096	146.3	147.3	3.6	4.2	3.9	340100	1433	-11	1.0	6.4	-3.7	-1.9	-1.0	-3.9
1133	152.5	153.2	6.2	5.8	6.0	315400	1731	3	0.9	8.4	-2.6	-5.9	-0.7	8.0
1135	153.3	154.0	3.8	4.0	3.9	351958	2390	0	1.1	8.5	-2.3	-5.7	-0.7	3.9
1142	149.6	151.6	9.6	3.5	6.6	328700	1458	3	1.1	7.9	-3.7	-0.8	-2.0	3.5
1151	162.9	162.9	1.0	1.4	1.2	332600	2242	-3	1.0	7.0	-1.4	4.6	0.0	6.0
1154	133.3	134.5	0.4	6.9	3.6	324000	1895	8	0.9	6.9	-1.9	8.8	-1.2	6.9
1157	163.3	159.3	2.4	2.5	2.5	347500	1397	5	1.0	7.4	-4.7	2.8	4.0	6.9
1158	155.2	156.4	-0.7	2.8	1.1	333500	1159	-3	1.3	8.8	-3.3	3.9	-1.2	6.9
1163	143.6	143.6	7.4	4.4	5.9	326900	1731	3	0.9	12.5	-3.2	-8.1	0.0	8.0
1166	152.6	149.6	3.4	5.2	4.3	354100	1120	0	1.1	7.8	-3.6	5.2	3.0	6.3
1180	158.2	157.2	8.1	7.2	7.7	351900	951	6	1.1	8.1	0.1	-1.4	1.0	5.9
1200	162.7	158.0	9.3	9.7	9.5	325725	1370	0	1.0	10.3	-3.3	-1.2	4.7	6.5
1208	125.0	120.4	4.1	8.5	6.3	335200	994	2	1.1	9.5	-1.6	4.6	4.6	3.9
1214	165.2	166.8	3.4	3.4	3.4	372000	2617	9	1.0	11.3	-1.4	3.9	-1.6	8.9
1228	156.1	158.8	2.1	6.3	4.2	361000	1747	-4	0.9	12.4	-3.9	-9.1	-2.7	7.5
1232	149.5	147.9	3.2	-1.6	0.8	367668	2994	13	1.1	11.3	-0.5	-5.1	1.6	8.9

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LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN PORT FPS	STBD FPS	AVG FPS	WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
87	165.5	158.0	2.15	3.41	2.78		1772	-11	1.0	9.0	-4.8	-10.8	7.5	-10.6
112	143.9	138.2	-0.03	5.31	3.07	335000	1162	-12	1.2	11.8	-5.5	2.2	5.7	-11.7
116	155.2	152.7	2.68	2.27	3.08		2284	1	0.9	10.6	0.0	-2.9	2.5	-5.4
127	150.4	142.0	4.15	5.77	5.30	333000	816	-9	1.0	11.2	-1.7	-2.3	8.4	-10.0
136	159.7	155.9	5.43	1	3.76	340000	868	-4	1.2	11.9	0.5	-4.4	3.8	-7.1
150	171.5	156.8	3.2	6.87	5.10	340000	1367	-7	0.9	8.6	-5.3	1.6	14.7	-8.5
191	163.4	156.3	2.07	2.2	2.14		991	-14	1.0	7.5	-1.9	-5.9	7.1	-8.4
278	157.3	153.9	7.22	5.73	6.47		1806	-9	0.9	12.9	-4.6	-8.8	3.4	-4.9
293	152.1	144.4	2.62	4.42	3.52	332000	2258	-9	1.0	13.0	-2.5	-3.1	7.7	-12.9
294	147.4	139.9	0.92	2.92	1.92	315000	1817	-4	1.1	13.2	-2.2	-0.1	7.5	-13.0
314	164.4	158.3	6.63	5.42	6.02	328519	1516	-5	1.0	9.9	-3.5	-4.7	6.1	-5.1
426	162.7	149.9	6.75	2.28	4.51	336000	1711	13	1.0	7.9	-1.7	-7.6	12.8	-2.3
436	154.9	143.6	1.55	1.49	1.52	342000	2738	4	0.9	9.2	-1.6	0.1	11.3	-6.5
439	167.5	150.1	2.35	2.49	2.42	324000	3111	-1	1.0	9.9	-1.9	-8.4	17.4	-7.7
451	154.1	146.4	0.23	1.79	1.01	334000	2458	-9	1.1	9.7	-2.5	-8.8	7.7	-6.4
454	162.2	153.5	4.24	4.21	4.22	326000	3290	-17	1.0	9.3	-0.9	-13.1	8.7	-5.0
504	158.6	149.6	2.03	1.84	1.93	360396	2413	-5	1.0	7.1	-3.6	-11.1	9.0	-0.8
568	151.9	143.7	1.88	4.37	4.11	352000	1440	-8	1.0	10.8	-5.8	-4.7	8.2	-8.8
584	139.8	129.4	3.39	4.77	4.08		1420	-8	1.0	13.2	-3.0	-2.5	10.4	-6.0
589	139.3	121.9	2.96	1.71	2.10	348000	2767	-3	1.1	10.6	-3.3	-0.8	17.4	-4.7
604	146.7	134.5	2.14	1.57	2.28	340000	2162	2	1.1	9.4	-4.6	-2.2	12.2	-4.4
610	147.8	130.8	3.06	3.04	3.05		1941	-4	1.0	9.7	-1.2	4.6	17.0	0.0
612	152.0	142.5	2.79	2.38	2.59	310000	830	-4	1.1	11.5	0.1	-0.3	9.5	-5.5
622	156.2	149.4	0.4	3.65	2.02		2272	-4	1.0	11.1	-1.8	-4.7	6.8	-1.7
744	145.0	146.0	1.78	3.96	3.05	316323	2699	12	1.0	8.7	-1.9	1.9	-1.0	9.9
754	146.2	140.7	2.13	1.92	3.10	333000	2359	2	1.0	11.6	0.6	-3.2	5.5	9.5
774	140.2	139.2	3.38	5.46	3.98	335000	1118	-2	1.0	11.8	-2.0	3.5	1.0	5.9
780	157.2	161.8	4.45	4.59	4.52	341000	1627	0	1.0	8.9	-4.0	-3.5	-4.6	3.9
783	161.9	166.8	4	2.54	3.64	340000	871	-5	1.2	12.1	-0.6	0.8	-4.9	4.9
796	145.3	149.1	1.43	3.41	2.42	340000	3222	0	0.9	12.0	1.9	-6.5	-3.8	5.9
955	163.1	167.0	3.32	5.29	4.31		1489	-6	1.0	9.2	0.4	-2.7	-3.9	0.8
959	162.9	165.9	2.96	3.74	3.35	336000	1295	-15	1.1	11.4	-3.6	2.3	-3.0	5.2
973	154.0	149.0	5.82	4.58	5.20		640	3	1.2	11.2	-6.9	9	5.0	8.7
976	163.8	160.3	3.52	1.99	2.27	343820	1414	7	1.2	9.7	-6.9	1.4	3.5	4.9
981	165.5	167.5	4.89	5.99	5.44	331000	1727	1	0.8	9.0	-3.2	-6.4	-2.0	3.5

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LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN			WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
			PORT FPS	STBD FPS	AVG FPS									
994	141.0	142.8	3.2	4.59	3.36	343000	1966	3	1.0	11.7	-0.2	1.6	-1.8	6.8
1153	148.6	146.2	0.03	1.88	0.95		2171	5	1.0	11.2	-0.8	8.1	2.4	6.6
1178	140.0	140.0	2.07	2.98	2.52	336000	1153	-1	1.0	10.8	-1.0	0.9	0.0	11.0
1183	155.5	151.8	3.53	2.16	1.30	335000	959	4	1.2	8.6	3.9	-3.3	3.7	9.3

LANDING DATA MODEL McDONALD DOUGLAS MD-11 AIRCRAFT
FAA SURVEY HONOLULU INTERNATIONAL AIRPORT

LNDG NO.	POWER APPROACH AIRSPEED KNOTS	CLOSURE SPEED KN	SINKING SPEED AT TOUCHDOWN PORT FPS	STBD FPS	AVG FPS	WEIGHT LBS	RAMP TO TD DIST FT	RUNWAY OFF CENTER FEET	GLIDE SLOPE ANGLE TD DEGREE	PITCH ANGLE TD DEGREE	ROLL ANGLE TD DEGREE	YAW ANGLE TD DEGREE	WIND PAR KNOTS	WIND PERP KNOTS
363	151.3	144.4	5.1	4.3	5.9	378700	1669	-5	1.1	7.9	-5.9	-8	6.9	-4.0
404	169.3	159.7	1.6	4.3	3.0	386466	1891	-9	1.3	7.9	-1.1	-0.4	9.6	-5.3
524	141.0	134.4	2.8	8.5	5.7		1148	-9	1.1	6.8	-4	1.1	6.6	-4.6
685	148.0	150.6	1.2	2.4	1.8	338000	2402	-1	1.1	8.6	-2	-8.1	-2.6	-3.1
709	159.9	152.0	3.5	3.7	3.6	368500	1891	-4	0.8	6	0.4	3.1	7.9	-1.4
869	170.9	173.0	8.1	5.1	6.6	398400	2278	6	0.9	8.2	-3.8	-2.5	-2.1	4.5
892	157.2	158.0	1.5	2.1	1.8	369000	2188	-9	1.1	6.3	-4.1	-2.6	-0.8	-2.9
1044	151.2	154.1	1.5	0.9	1.2	381920	2393	1	1.1	6.4	-4.1	-4.9	-2.9	4.1
1146	167.4	166.7	2.3	0.4	1.3	390906	1036	5	1.2	8.4	0.9	-3.9	0.7	8.0

APPENDIX B—LANDING PARAMETER SURVEY DEFINITIONS

Sink Speed V_V—The sink speed of the aircraft landing gear wheel just prior to touchdown. Sink speed is reported for each landing gear individually, that is for the port, starboard, and nose wheels just prior to individual runway contact. In addition, the average sink speed of the aircraft main landing gear is calculated just prior to touchdown of the first main landing gear wheel. Sink speed is determined from image data. The symbols used to identify aircraft sink speed are as follows:

V_{V_A} - average sink speed
V_{V_S} - sink speed of the starboard main wheel
V_{V_P} - sink speed of the port main wheel

The values of aircraft sink speed are reported in feet per second (ft/sec).

Wind Speed V_W—Wind Speed is the wind velocity measured by the survey team's instrumentation. A head wind is defined as the positive direction for the parallel component of wind speed. The perpendicular component of wind speed and the crosswind is also reported. Wind speed is reported in knots.

Closure Speed V_C—The closure speed is the speed determined by the change in the aircraft's range from the camera. It is reported parallel to the runway centerline. Closure speed is reported with respect to the ground and is reported in knots. Closure speed is calculated from image measurements.

Approach Speed $V_{P'AF}$—The value of approach speed reported is the algebraic sum of closure speed and component of wind speed parallel to the runway centerline. The value of approach speed is the aircraft forward velocity with respect to the air mass and is reported in knots.

Aircraft Pitch Angle θ_p—The aircraft pitch angle is measured between the aircraft reference line and a line parallel to the runway. Positive values of pitch angle are reported for an aircraft with a nose up attitude. Pitch angle is determined from image data and is reported in degrees.

Aircraft Roll Angle θ_r—The aircraft roll angle measured between the aircraft reference line and a line parallel to the runway. Positive values of roll angle are reported for an aircraft whose starboard wing is down. Roll angle is determined from image data and is reported in degrees.

Aircraft Yaw Angle Yaw_{td}—The yaw angle is the angle between the aircraft centerline and the aircraft flight path at the point of first main wheel touchdown. Positive yaw angle is defined to be that orientation where a clockwise rotation of the flight path vector causes the vector to coincide with the aircraft centerline using a minimum angular rotation. Yaw angle is determined from image data and is reported in degrees.

Aircraft Off-Centerline Distance Y—The aircraft off-centerline distance is the perpendicular distance measured between the aircraft centerline and the centerline of the runway. This value is calculated from image data just prior to first main wheel touchdown. Positive values of this quantity indicate that the aircraft landed on the port side of the runway centerline and is reported in feet.

Distance From Runway Threshold to First Main Wheel Touchdown XW—The distance between the runway threshold and the point of first main wheel touchdown is determined from image data and is reported in feet.

Aircraft Instantaneous Glideslope Angle β_{V_V} —This angle is determined just prior to first main wheel touchdown and is reported in degrees. The value of average sink speed (VVA) and closure speed (Vc) are used to define the instantaneous glide slope. These values are entered into the equation

$$\beta_{V_V} = \arctan\left(\frac{V_{V_A}}{Vc}\right)$$

Note: A consistent set of units (ft/sec) must be used in this equation.

Landing Weight W—The landing weight reported in the survey is an estimate provided by the aircraft operators. The value of this quantity is reported in pounds

List of Subscripts:

P	-	Port
S	-	Starboard
N	-	Nose wheel
A	-	Average
r	-	Roll
p	-	Pitch

APPENDIX C—COMPARISON OF FAA VIDEO LANDING SURVEY SYSTEM WITH THE BOEING MD-90 FLIGHT TEST INS SYSTEM

Research Objective: To provide a verification of the accuracy of the vertical velocity results from the FAA Video Landing Parameter Surveys

Background: The FAA and US Navy have been jointly conducting a number of video landing parameter surveys at high capacity commercial airports. To date surveys have been conducted at John F. Kennedy (JFK) International, Washington National (DCA) (now Reagan), Honolulu (HNL) International, and London City (LCY) Airports, and plans are in place for additional surveys. After receiving published data from the JFK survey and preliminary data from DCA, the Boeing Aerospace Corporation has many concerns regarding the accuracy of the results from these Joint FAA/Navy Surveys. Specific concerns include:

- FAA/Navy Video Landing Parameter Survey Results were grossly overestimating vertical velocity.
- Due to measurement errors, FAA/Navy frequency distributions were not representative of the distribution Boeing assumes.
- Higher vertical velocity measurement errors exist at higher vertical velocities.

Approach: The FAA and Boeing Douglas Products Division (DoD) agreed to conduct a Fly-off Comparison Survey at Atlantic City International (ACY) Airport during the spring of 1998. Boeing ferried its MD-90 airplane equipped with a INS Flight Test System and flight test team to ACY while the FAA/Navy setup a temporary video landing facility on runway 13.

Accomplishment Description: Over 70 complete stop landings were flown during a 1-week period. These landings were simultaneously recorded on the Boeing flight test system and the FAA/Navy video landing parameter system. The resultant data were subsequently processed at Boeing DPD and the FAA/Navy facilities. Figure C-1 shows a good correlation of results from the respective systems. While there were some individual landing differences, overall survey vertical velocities were within FAA/Navy and Boeing assumed one half ft/sec tolerance. The frequency distribution of FAA/Navy Vertical Velocity Data closely matches similar data from the Boeing DPD (see figure C-2).

Significance: Due to the Boeing concerns regarding the accuracy of the FAA/Navy video survey results, the FAA

- Performed quasi-static calibration of FAA/Navy video system at NAWC Warminster
- Delayed Publication of DCA Report
- Stopped Data Processing of HNL and LCY Data
- Provided a complete FAA/Navy requested System Description and Representative Technical Data to Boeing to conduct a comprehensive review of Navy Data Reduction Algorithms and Procedures

- Agreed to Fly-off Comparison in April 98

Expected Results: Continuation of the publication of reports and the conduct of additional surveys to collect new data from which updated sink speed and other landing parameter certification requirements can be developed.

Reference: Barnes, T., DeFiore, T., and Micklos, R., "Video Landing Survey – John F. Kennedy International Airport," DOT/FAA/AR-96/125, July 1997

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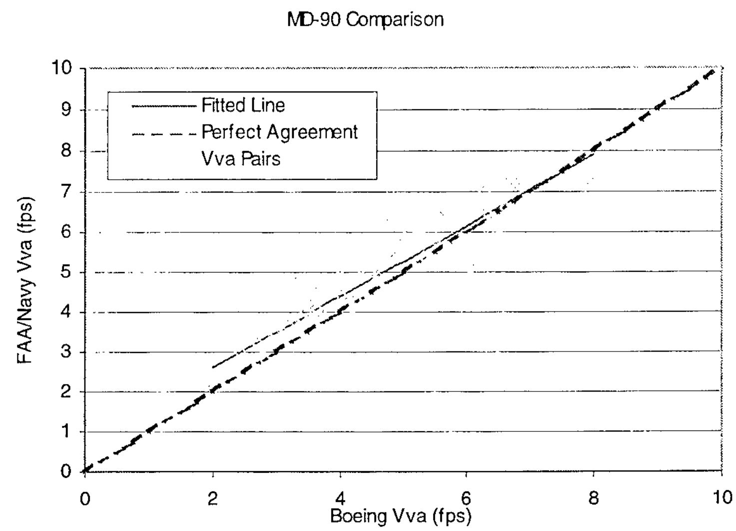

FIGURE C-1. INDIVIDUAL LANDING CORRELATION (r = 0.93)

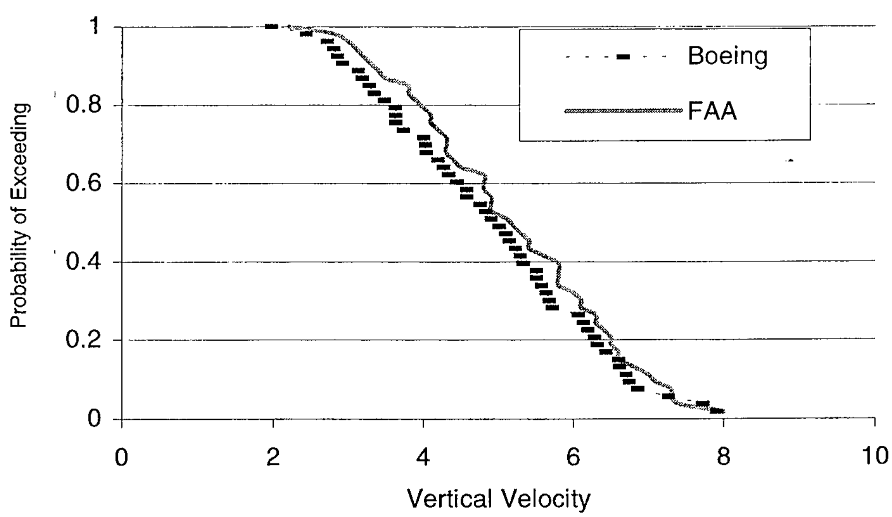

FIGURE C-2. VERTICAL VELOCITY FREQUENCY DISTRIBUTIONS